SPATIAL, SEASONAL, AND SIZE-DEPENDENT VARIATION IN THE DIET OF SACRAMENTO PIKEMINNOW IN THE MAIN STEM OF CHORRO CREEK, CENTRAL COAST CALIFORNIA

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TITLE:	SPATIAL, SEASONAL, AND SIZE-DEPENDENT VARIATION IN THE DIET OF SACRAMENTO PIKEMINNOW IN THE MAIN STEM OF CHORRO CREEK, CENTRAL COAST CALIFORNIA
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ABSTRACT

SPATIAL, SEASONAL, AND SIZE-DEPENDENT VARIATION IN THE DIET OF SACRAMENTO PIKEMINNOW IN THE MAIN STEM OF CHORRO CREEK, CENTRAL COAST CALIFORNIA

Brian G. Dugas

This study examined the diet composition of ninety-nine Sacramento pikeminnow (150-410 mm [5.9-16 in] fork length [FL]) collected from the upper and lower main stem of Chorro Creek, Morro Bay Watershed, California in 2006. The goal of this study was to characterize the spatial and seasonal variability in the diet of Sacramento pikeminnow within Chorro Creek and to determine what proportion of the diet is represented by rainbow trout (*Oncorhynchus mykiss*) and their anadromous form (steelhead). Prey was identified in 88% of the samples collected in the early season and 84% of the samples collected in the late season. Fish and/or scales were identified in 12% of the samples collected. Sacramento pikeminnow consumed a wide variety of prey; the diversity of individual diets was higher in the lower main stem than the upper. Overall, diet diversity increased with Sacramento pikeminnow length. In both the early and late season, crayfish formed the largest part of the diet of large Sacramento pikeminnow (>250 mm [9.8 in]). There was a slight increase in the proportion of fish in the diet during the late season, and tendency for cannibalism which was primarily observed in the upper main stem of Chorro Creek. In summary, the overall results of this study support the conclusion that Sacramento pikeminnow are not significant predators of *O. mykiss* in natural stream conditions. However, conclusions about the ability of Sacramento

pikeminnow in Chorro Creek to reduce *O. mykiss* populations will require further information on the prey selection of Sacramento pikeminnow when juvenile *O. mykiss* and adult pikeminnow are abundant.

ACKNOWLEDGEMENTS

Funding for this work was provided by the California Department of Fish and Game and the Morro Bay National Estuary Program. The field work could have not been completed without the assistance from a number of individuals, especially Freddy Otte of HydraTerra Consulting and Mike Hill, Dave Highland, and Mike Elkins of the California Department of Fish and Game. Sampling supplies and laboratory equipment were provided by Royden Nakamura of Cal Poly's Biological Sciences Department. Special thanks to Krista Fahy, Associated Curator of the Santa Barbara Natural History Museum, Kenny Gilliland, and Freddy Otte for assistance in identification and processing of foregut samples. Thanks also to Jeff Sklar of the Cal Poly Statistics Department for assistance in the statistical analysis. Early versions of this paper were reviewed by my thesis committee members: Dr. James Vilkitis (Chairperson) and Dr. Royden Nakamura of Cal Poly, and Dr. David Pilliod of the USGS Forest and Rangeland Ecosystem Science Center, and Freddy Otte. Lastly, I would like to thank my family Virginia, Logan, and Joaquin Dugas for all of their patience and support during the completion of this project.

- *Dedicated to Reggie Dugas (R.I.P. Lil Buddy)* -

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List of Units

af	Acre Feet
C°	Degrees Celsius
F°	Degrees Fahrenheit
ft	Feet
ft^3/s	Cubic Feet per Second
g	Grams
ha	Hectares
in	Inches
km	Kilometers
m	Meters
m^3	Cubic Meters
m^3/s	Cubic Meters per Second
mi	Miles
mi^2	Square Miles
mm	Millimeters

Chapter 1 – Introduction

Chorro Creek and its principal tributaries have historically provided significant migration, spawning, and rearing habitat for native rainbow trout (*Oncorhynchus mykiss*) and their anadromous form (steelhead), but habitat degradation, water withdrawal, blockage of migration, and introduction of non-native species are believed to have contributed to a decline in their overall abundance. For the purposes of this study, native rainbow trout and steelhead are referred to collectively as *O. mykiss* which is inclusive of both populations within Chorro Creek and elsewhere. The primary non-native fish species of concern within the Chorro Creek watershed is the Sacramento pikeminnow (*Ptychocheilus grandis*) (Payne and Associates 2007). The Sacramento pikeminnow (commonly known as squawfish) is native to the Sacramento-San Joaquin delta and the Salinas River drainage in central California (Moyle 2002).

It is believed that Sacramento pikeminnow were originally introduced into the Chorro Creek system via fishermen utilizing pikeminnow as bait in the Chorro Reservoir, or via an aqueduct connecting the Chorro watershed with the upper Salinas River prior to 1975 (Highland, pers. comm., Moyle 2002). The Sacramento pikeminnow utilizes much of the same habitat as *O. mykiss* in the mainstem of Chorro Creek and similarly are believed to migrate up tributaries in the spring months to spawn (Harvey and Nakamoto 1999). Although *O. mykiss* and Sacramento pikeminnow apparently coexist in the Sacramento River and other drainages, they are believed to be having a negative impact on the threatened *O. mykiss* population within the Chorro Creek watershed by direct predation and competition for habitat.

As juveniles, Sacramento pikeminnow feed on small aquatic insects, but fish larger than 200 mm (7.8 in) feed almost exclusively on fish and crayfish (Brown and Brasher 1995). In the Eel River, Brown and Moyle (1997) concluded that the Sacramento pikeminnow only preyed upon significant numbers of juvenile salmonids under localized conditions. Further analysis of the diet of Sacramento pikeminnow within the Eel River supported the conclusion that pikeminnow are not significant predators of salmonids under natural stream conditions (Nakamoto and Harvey 2003). Overall, salmonids represented <10% of the diet of Sacramento pikeminnow collected from the Eel River between 1986 and 1990, and 1995 and 1997, respectively (Brown and Moyle 1997, Nakamoto and Harvey 2003). In summary, Nakamoto and Harvey (2003) concluded that stream reaches with thermal regimes and physical attributes that allow occupation by both large Sacramento pikeminnow and *O. mykiss* in summer are likely "hotspots" for predation by the former.

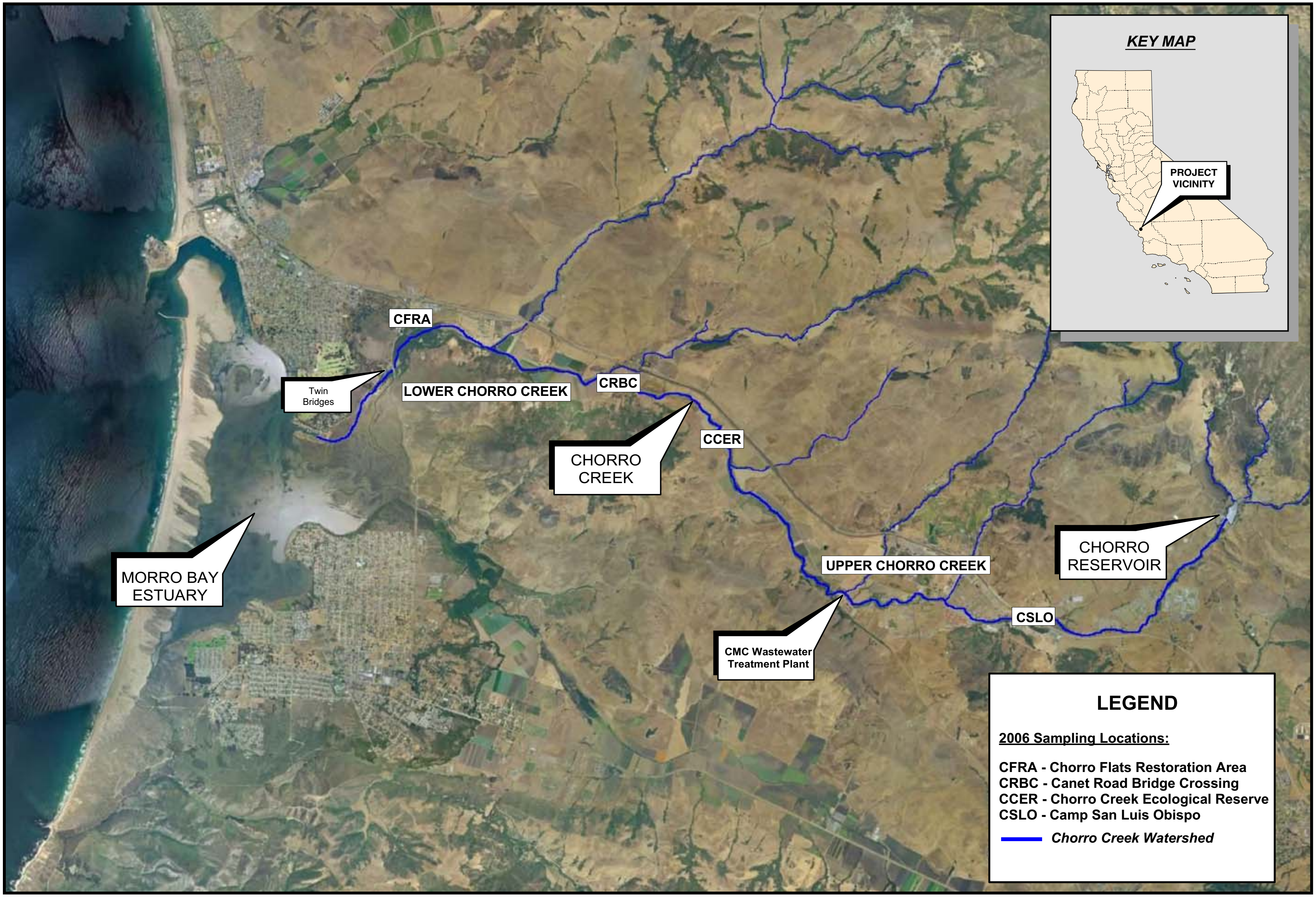
Chorro Creek is a small, coastal stream that maintains year-round flows due to artifical water sources including continuous discharge from the Califorina Men's Colony (CMC) Wastewater Treatment Plant which represents 50 percent of stream flows during the dry season (Morro Bay National Estuary Program 2000). Nutrient loading in Chorro Creek surface water contribute to the growth of nuisance algae and decreased dissolved oxygen levels which are detrimental to native *O. mykiss*. Such conditions coupled with localized habitat degradation have allowed Sacramento pikeminnow to expand their distribution throughout the Chorro Creek watershed which has led resource managers, including the California Department of Fish and Game to consider the Sacramento pikeminnow as one of the primary limiting factors of *O. mykiss* abundance within the system. Specifically, juvenile *O. mykiss* out-migrating from the tributaries of Chorro Creek are believed to be exposed to high levels of predation from large Sacramento pikeminnow within the main stem of Chorro Creek. The goal of this study was to characterize the spatial and seasonal variability in the diet of piscivorous Sacramento pikeminnow within Chorro Creek and to determine what proportion of the diet is represented by *O mykiss*, while incorporating variation attributable to body size.

Chapter 2 – Literature Review

2.1 Study Site

A total of four sampling stations were established within the mainstem of Chorro Creek: Camp San Luis Obispo (CSLO), Chorro Creek Ecological Reserve (CCER), Canet Road Bridge Crossing (CRBC), and the Chorro Flats Restoration Area (CFRA). For the purpsoes of this study, the CSLO and CCER were considered "upper" Chorro Creek and the CRBC and CFRA were considered "lower" Chorro Creek, respectively (Figure 1, Appendix A). Chorro Creek drains the northern two-thirds of the Morro Bay watershed, an area of approximately 11,420 ha (44 mi^2). The main stem of Chorro Creek flows southerly to the Chorro Reservoir on CSLO and continues in a southerly direction to Highway 1 then flows northwesterly south of Highway 1 into Morro Bay, California (Figure 1). The watershed is bordered on the northeast by the Santa Lucia Range and to the southwest by a series of volcanic peaks known as Park Ridge. Two of the peaks (Black Hill and Cerro Cabrillo) form a narrow, through which Chorro Creek drains (Vilkitis and Woodley 1984).

The Chorro Creek watershed is typical of other Central California coastal areas and has a Mediterranean climate characterized by mild to warm temperatures and extended dry periods with little rainfall from May to October. Most of the rainfall, and consequently runoff and flooding, occurs in the rainy season period between November and April (Philip Williams & Associates 2005). At least five major tributaries contribute flow to the main stem of Chorro Creek, in particular San Bernardo Creek, San Luisito Creek, Pennington Creek and Dairy Creek. The upper portion of Chorro Creek below the CMC Wastewater Treatment Plant (Figure 1) provides a significant percentage of the



SOURCE: AirPhotoUSA (1997-2006)

SITE VICINITY AND LOCATION MAP

FIGURE 1

NORTH
Not to Scale

summer nursery habitat for *O. mykiss* in the form of pools, and sustains about 60 percent of the juvenile *O. mykiss* population (Morro Bay National Estuary Program 2000). Summer water temperatures (i.e., June-August) range from 14-21°C (58-71°F), within acceptable limits for *O. mykiss* (Moyle 2002). In the main stem, water temperatures were 16-21.6°C (61-71°F) during the sampling period from February to late October 2006.

The CMC operates and manages the Chorro Reservoir located in the upper main stem of Chorro Creek (Figure 1). Constructed in 1941 to store runoff water for Camp San Luis Obispo (California National Guard), Chorro Reservoir had an original storage capacity of 262,700 m^3(213 af). However, due to sediment accumulation, capacity in 1994 was estimated at less than 185,000 m^3 (150 af). Until the early 1990s, the CMC operated a suction dredge to remove sediment, but no accurate estimates of sediment amounts are available. The dredge material was piped to basins on the eastern side of the reservoir, dried, and then removed to other areas on Camp San Luis Obispo. Imported water from Whale Rock Reservoir is stored in the Chorro Reservoir and supplemented with water from the State Water Project and water extracted from nearby wells.

The California State Water Resources Control Board enforces release-requirements on Chorro Reservoir. Specifically, if Chorro Creek is flowing at >0.06 m^3/s (2 ft^3/s) above Chorro Reservoir, then 0.03 m^3/s (1 ft^3/s) must be released from the reservoir dam. Conversely, if Chorro Creek is flowing <0.06 m^3/s above the reservoir, then one-half of the flow must be released below the dam (Phillip Williams and Associates 2005). CMC also operates a wastewater treatment facility that disposes its effluent into the main stem of upper Chorro Creek, Cal Poly San Luis Obispo and the Dairy Creek Golf Course for mitigation purposes (Figure 1). The CMC has dedicated

0.02 m^3/s (0.75 ft^3/s) or the entire output of its treatment plant (whichever is less) for the purpose of maintaining downstream habitat, which when combined with summertime discharge from Chorro Reservoir provides approximately 50 percent of the flow in Chorro Creek (Morro Bay National Estuary Program 2000).

Anthropogenic activities within the watershed consist of multiple-use agricultural lands (e.g., rangelands, row crops, etc.), low-density residential and commercial uses which include but are not limited to the CMC, Camp San Luis Obispo, Cuesta Community College, Dairy Creek Golf Course, and various County of San Luis Obispo administrative buildings and municipal facilities. Consequently, elevated levels of nitrates and phosphates in Chorro Creek surface water contribute to the growth of nuisance algae and decreased dissolved oxygen levels have been recorded in violation of Regional Water Quality Control Board (RWQCB) Basin Plan water quality objectives. Nutrient sources include septic systems, fertilizers, urban runoff and animal waste from ongoing agricultural operations throughout the watershed (Morro Bay National Estuary Program 2000). Rapid bioassessment sampling conducted by the Morro Bay Volunteer Monitoring Program in Chorro Creek from 2006 through 2007 indicated a spatial trend of decreasing diversity in the percentage of sensitive macroinvertebrate orders (Ephemeroptera, Plecoptera, and Tricoptera [% EPT Index]) which is indicative of poor water quality and impaired watersheds (Morro Bay National Estuary Program 2008). The Morro Bay National Estuary Program bioassessment sampling sites include the Chorro Reservoir Dam, Chorro Creek Ecological Reserve, and Twin Bridges located immediately upstream of the Morro Bay Estuary (Figure 1) which encompassed the sampling reaches of this study.

Approximately 60 percent of the Chorro Creek watershed is classified as rangeland and 20 percent is considered brushland (Morro Bay National Estuary Program 2000). Vegetation communities of the lower elevations are comprised of California annual grassland, coastal sage scrub, riparian scrub/woodland, oak woodland, and oak savanna, and transition into chaparral and mixed oak-conifer forests along the upper elevations. Due to past anthropogenic activities, the riparian habitat of the main stem of Chorro Creek tends to increase with greater structural complexity and density from the upper to the lower main stem. Specifically, the portion of the main stem from the CCER down to the CFRA (Figure 1) maintains a relatively continuous riparian corridor dominated by willow scrub (*Salix* sp.) with varying degrees of density, canopy cover, and buffers from adjacent agricultural operations and low density single-family residences. A comprehensive enhancement project was implemented from 1998-2002 and involved the recreation of a large portion of the lower Chorro Creek floodplain, which is now considered the Chorro Flats Restoration Area. The enhancement project resulted in the creation of a multi-channel stream system dominated by willow scrub habitat and perennial wetlands. Conversely, the upper portion of the main stem of Chorro Creek which transects the CMC and CSLO is characterized by fragmented and degraded willow scrub habitat including areas of entirely denuded stream banks and pool habitat areas without riparian cover (i.e., Highway 1 bridge crossing).

2.2 Common Freshwater and Anadromous Fishes of Estero Bay

Historically, Chorro Creek is known to support several federally-listed fish species including the anadromous south-central California coast steelhead trout DPS (Distinct Population Segment) (*O. mykiss irideus*) and the tidewater goby (*Eucyclogobius newberryi*) which is an estuarine species known to occur up to 4.8 km (3 mi) inland of coastal waters. *O. mykiss irideus* is listed as Threatened under the Endangered Species Act (ESA) by the National Marine Fisheries Service (NMFS) and tidewater goby is listed as Threatened by the U.S. Fish and Wildlife Service (USFWS) under the ESA. *O. mykiss irideus* rely on Chorro Creek, as well as its five tributaries, for spawning habitat and rearing of their progeny with some remaining as residents. Other native fishes of Chorro Creek include the prickly sculpin (*Cottus asper*), coast range sculpin (*C. aleuticus*), Pacific staghorn sculpin (*C. armatus*), threespine stickleback (*Gasterosteus aculeatus*), speckled dace (*Rhinichthys osculus*), and Pacific lamprey (*Lampetra tridentata*). At least five introduced fishes are known to have established reproducing populations within Chorro Creek, including the Sacramento pikeminnow, Sacramento sucker (*Catostomus occidentalis*), common carp (*Cyprinus carpio*), mosquito fish (*Gambusia affinis*), and fat-head minnow (*Pimephales promelas*), with the Sacramento pikeminnow representing the most widespread and abundant of the introduced fishes within Chorro Creek (Payne and Associates 2001).

Bluegill (*Lepomis macrochirus*), green sunfish (*L. cyanellus*), largemouth bass (*Micropterus salmoides*), spotted bass (*Micropterus punctulatus*), brown bullhead (*Ameirus nebulosus*), mosquito fish, and golden shiner (*Notemigonus crysoleucas*) are all introduced species which are reported to inhabit Chorro Reservoir. However, only bluegill, largemouth bass, spotted bass, Sacramento pikeminnow, sculpin, and mosquito fish were detected during intensive sampling efforts within the Chorro Reservoir in 2005 (F. Otte, pers. comm.). Bluegill and green sunfish are occasionally encountered in the main stem of Chorro Creek and some of the larger tributaries. Based on surveys completed in 2001 and additional sampling efforts in 2006, common species identified in Chorro Creek included bluegill, sculpin, speckled dace, threespine stickleback, mosquito fish, Sacramento pikeminnow, Sacramento sucker, and *O. mykiss*. Bluegill, Sacramento pikeminnow, *O. mykiss*, speckled dace, and sculpin are also found in the tributaries to the Chorro Reservoir (F. Otte, pers. comm.).

2.3 Life History of Sacramento Pikeminnow

Sacramento pikeminnow are native to California's central valley and portions of the central coast, including the Salinas River watershed. They frequent clear, low-to mid-elevation streams and are most abundant in lightly disturbed streams featuring dense riparian vegetation, overhanging branches, slow pools, and undercut banks. Sacramento pikeminnow can be found in water temperatures in the range of 18-28ºC (64-84 ºF), though they are capable of withstanding extremes up to 38 ºC (100 ºF) and salinities as high as 8 ppt (Moyle 2002).

They are generally opportunistic and non-selective predators (Nakamoto and Harvey 2003). Sacramento pikeminnow that are greater than 150 mm (5.9 in) in length become increasingly piscivorous with size and consume a wide variety of fish species, including juvenile pikeminnow (Brown 1990). Larger Sacramento pikeminnow (>200 mm [7.8 in]) typically focus on fish and crayfish as primary prey, though they have been documented to prey upon snakes, lizards, frogs, lamprey ammocoetes, large stoneflies, and even small rodents. In the Sacramento-San Joaquin Delta, Sacramento pikeminnow became predominantly piscivorous at about 190 mm (7.5 in) (Nobriga and Feyrer 2007). Brown and Moyle (1991) and Brown and Basher (1995) found that California roach (*Lavinia symmetricus*) and *O. mykiss* reduce their vulnerability to Sacramento pikeminnow predation by shifting to shallower water (i.e., riffle habitat areas). Large Sacramento pikeminnow can counter this strategy and will frequently enter these habitats to forage at night (Harvey and Nakamoto 1999). Individual pikeminnow can move over 500 m (1,640 ft) during nighttime foraging excursions before returning to their home pools (Moyle 2002).

Sacramento pikeminnow are the largest members of the minnow family (Cyprinidae) and can reach lengths in excess of 1 m (3.3 ft) and live up to 16 years in lentic systems (Moyle 2002). The largest recorded Sacramento pikeminnow, found in Fresno County, measured 1,150 mm (45 in) and weighed 14.5 kg (32 lbs). Sacramento pikeminnow grow most rapidly in the first five years of life, especially in the summer months. In general, Sacramento pikeminnow are capable of reaching 50-85 mm (1.9-3.3 in) at the end of their first year, 100-150 mm (3.9-5.9 in) at the end of their second year, 170-250 mm (6.7-9.8 in) at the end of their third year, 240-270 mm (9.4-10.6 in) at the end of their fourth year, and 260-350 mm (10.2-13.8 in) at the end of the of their fifth year (Moyle 2002). Sacramento pikeminnow become sexually mature at age 3-4 and begin spawning in April-May within riffles and pool tails with gravel substrate. Fecundity is high with approximately 15,000-40,000 eggs per female measuring 310-650 mm (12.2-25.6 in) in length (Moyle 2002). Eggs typically hatch in a week or less and young fish gradually disperse into small schools and move into deeper water with time, often occupying protected riffles and fast water (Gard 2005).

2.4 Life History of *O. mykiss*

O. mykiss historically ranged from Alaska southward to the California-Mexico border, though current data suggests that the Ventura River is presently the southernmost drainage supporting substantial *O. mykiss* runs. Periodically, *O. mykiss* are reported within the Santa Clara River and Malibu Creek. Populations of *O. mykiss* in southern California are important in that they represent the southernmost portion of the native *O. mykiss* range in North America, having ecologically and physiologically adapted to seasonally intermittent coastal California streams. Optimal habitat for *O. mykiss* throughout its entire range on the Pacific Coast can generally be characterized by clear, cool water with abundant instream cover (e.g., submerged branches, rocks, and logs), well-vegetated stream margins, relatively stable water flow, and a 1:1 pool-to-riffle ratio (Raleigh *et al*. 1984). However, *O. mykiss* are occasionally found in reaches of streams containing habitat which would be considered less than optimal. *O. mykiss* within the central coast region begin moving up coastal drainages (including Chorro Creek) following the first substantial rainfall of the fall season typically entering freshwater from December to March. It is for this reason that the anadromous *O. mykiss* are considered winter run fish.

O. mykiss typically require cool, clear flowing water with clean gravel in which to spawn. Their primary food source, benthic macroinvertebrates (BMI) also require these general habitat conditions. Spawning typically occurs in the spring in pool tail or riffle areas that consist of clean coarse gravels. Deposited eggs incubate for approximately 3 to

4 weeks, with hatched fry rearing within the gravel interstices for an additional 2 to 3 weeks. Emergent fry rear at the stream margins near overhanging vegetation. Juveniles (smolts) after rearing for 1 to 3 years within freshwater and post-spawning adults out-migrate to the ocean from March to July, depending on stream flows. In general, juvenile *O. mykiss* can be found within Chorro Creek during all times of the year, while adults are more likely to be found from February to July.

2.5 *O. mykiss* Population Estimate

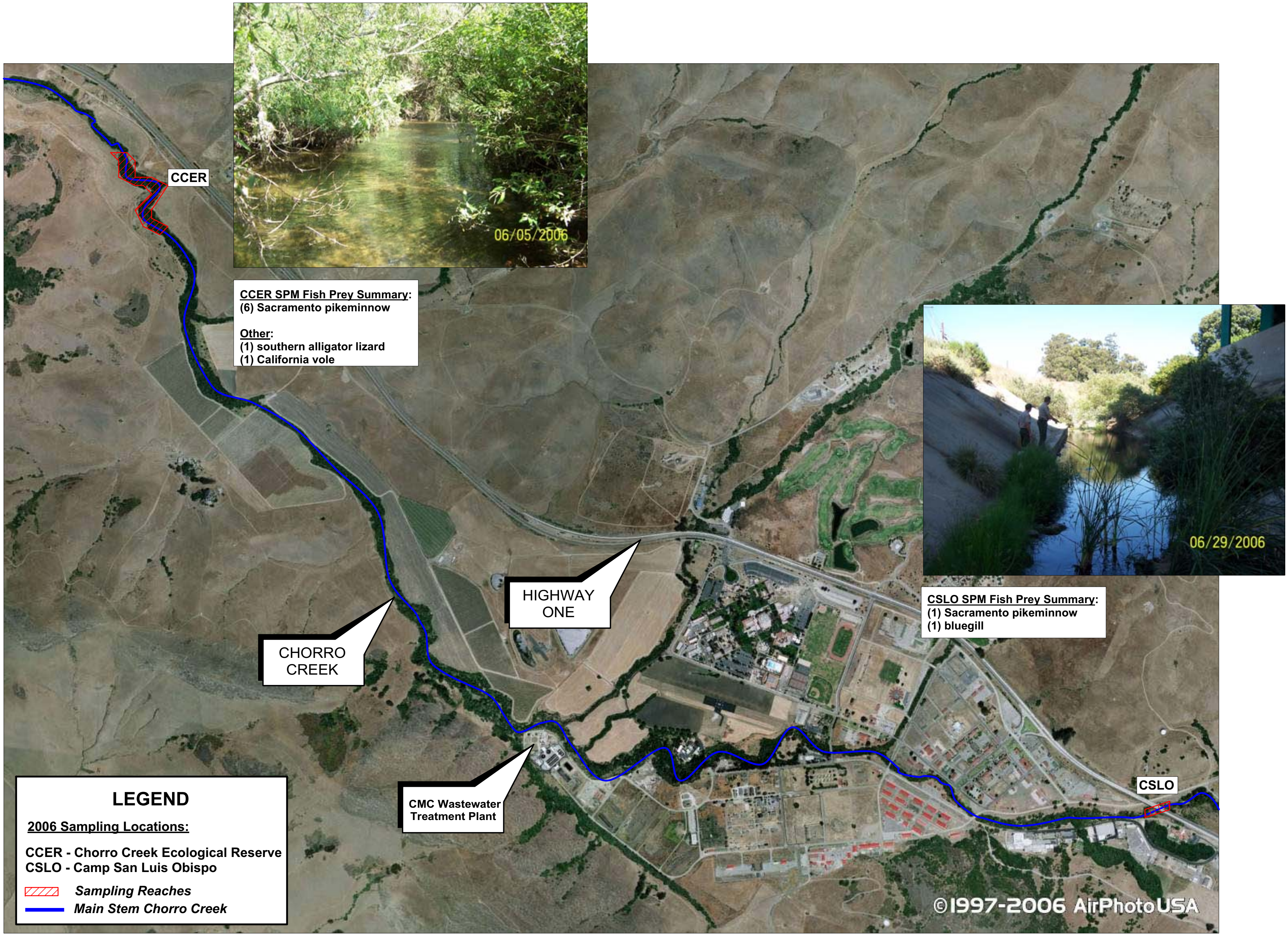
The last focused and comprehensive *O. mykiss* population survey completed within the Chorro Creek watershed was conducted in 2001 by Thomas R. Payne & Associates. The primary goal of the survey was to document the relative distribution and abundance of juvenile *O. mykiss* (and occurrence of other species) throughout accessible rearing habitat within Chorro Creek. The biologist team used snorkel surveys as the method for sampling all pool habitats along the main stem of Chorro Creek and selected tributaries. Their results showed an abundance estimate of 94-*O. mykiss*-per-1.6 km (1 mi) (>100 mm [3.9 in] in length) of surveyed pool habitat and an absence of *O. mykiss* young-of-the-year (<100 mm in length). In summary, a total of 221 *O. mykiss* >100 mm in length were observed within 20 pools surveyed in the main stem Chorro Creek (Payne and Associates 2001).

Sacramento pikeminnow were the most abundant species observed within Chorro Creek during the survey and were estimated at a density of approximately 1,000 to 3,000-pikeminnow-per-1.6 km (1 mi) throughout the lower 14.4 km (9 mi) of the main stem of Chorro Creek. It was undetermined whether the lack of young *O. mykiss* observed was due to water temperature, flow rates, or predation. A trial investigation that used underwater videography to observe the presence of *O. mykiss* in areas other then pools was also conducted. Results showed that *O. mykiss* may be utilizing untraditional habitat such as runs and riffles, in the presence of a predator. Brown and Moyle (1991) postulated that *O. mykiss* within the Eel River which had not experienced pikeminnow or any other piscivorous fish in their recent evolutionary history, shifted habitat due to risk of predation. Other species observed in relatively high abundance in the lower and middle portions of the Chorro Creek during the 2001 survey included threespine stickleback and speckled dace.

Chapter 3 – Field/Laboratory Methods

Sacramento pikeminnow samples were repeatably taken from each of the the four predesignated sampling stations within upper (CSLO, CCER) and lower (CRBC, CFRA) Chorro Creek from March through October 2006 (Figure 1, Appendix A). All sampling was completed with the assistance of California Department of Fish and Game (CDFG) staff and Freddy Otte of HydroTerra Consulting. Air and water temperature were recorded at each sample location in addition to the number and species of all other fish encountered during the sampling events (Table 1).

The primary capture technique was hook-and-line with barbless artificial lures to minimize inadvertent impacts to *O. mykiss*. We also sampled with electrofishing equipment on a number of occassions using a Smith-Root Model VII backpack electro-fishing unit powered by a 12-volt battery which sends a high-voltage, low-amperage electrical current (200 volts) through the surrounding water column. All fish within range of the electric field were temporarily immobilized and captured using long-handled dip nets. One unsuccessful seining event was also attempted at the CRBC which yielded poor fish capture per unit effort returns and was subsequently eliminated as a viable capture technique from the sampling program. Due to access issues, samples taken from the CSLO and CRBC were limited to pools and runs located immediately upstream and downstream of the respective crossings (<100 m [328 ft]), whereas sample sites at the CCER and CFRA allowed for larger sampling reaches up to 500 m (1,640 ft) in length (Figures 2 and 3). To further reduce the risk of electro-fishing and catch-and-release injuires to adult *O. mykiss* and eggs, no sampling was conducted from November through February per regulatory permit restrictions.

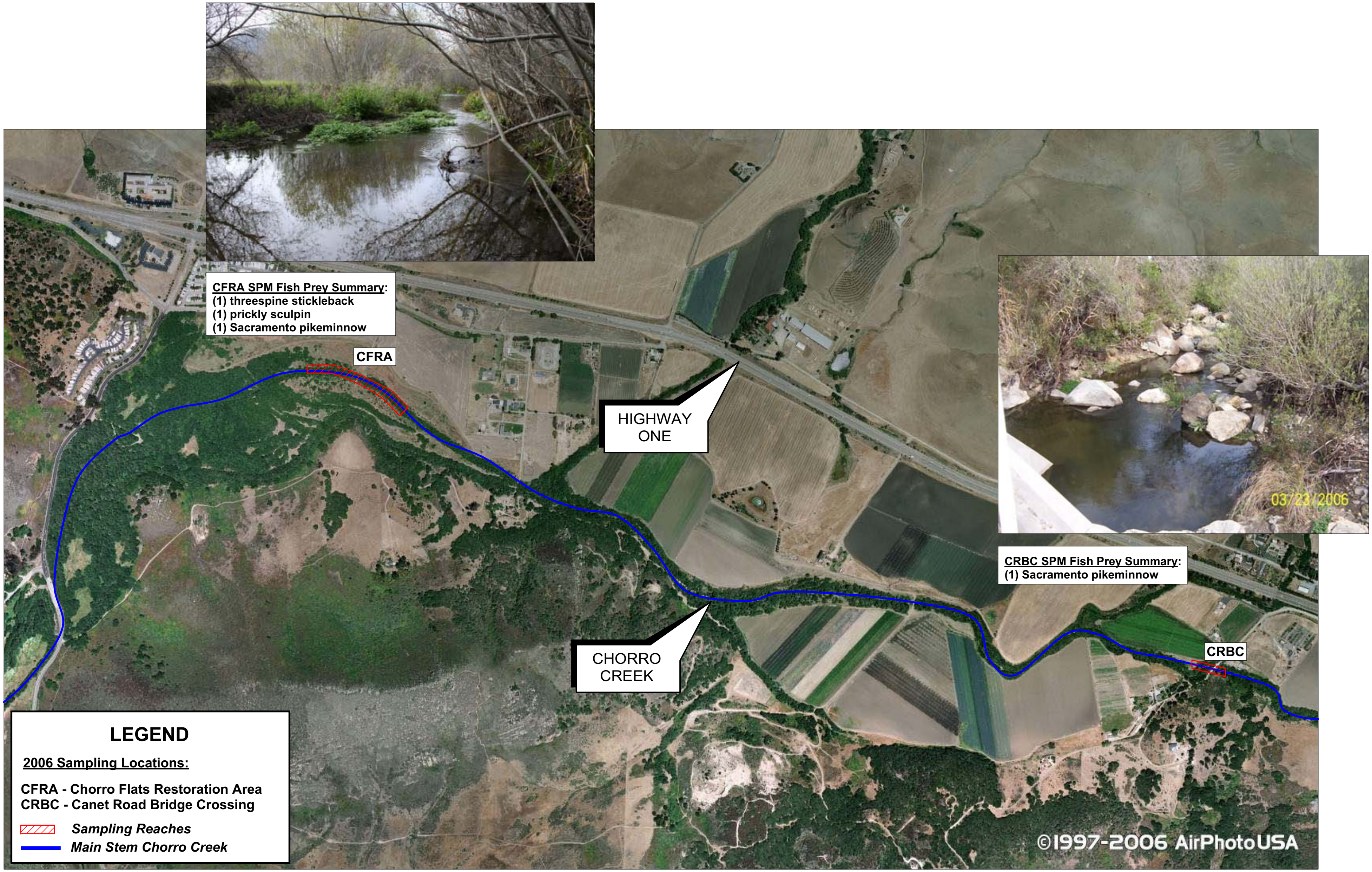


SOURCE: City of San Luis Obispo (2009)

NORTH
Not to Scale

UPPER CHORRO CREEK SAMPLING REACHES

FIGURE 2



SOURCE: City of San Luis Obispo (2009)

NORTH
Not to Scale

LOWER CHORRO CREEK SAMPLING REACHES
FIGURE 3

During each sampling run, all captured Sacramento pikeminnow were temporarily held in water filled buckets. Species-specific counts were recorded for other fish observed and/or captured during sampling (Table 1). All captured fish were identifed to species and were immediatley released, except for Sacramento pikeminnow and bluegill. The fork length, weight, and gape of Sacramento pikeminnow were measured and recorded. Fork length (FL) is defined as the length of the fish in mm from the tip of the lower jaw with the mouth closed and extending posterior to the notch between each lobe of the tail (Figure 4). Weight in grams was measured using an electronic scale. Gape is defined as the distance from inside the lower jaw upward to the inside of the upper jaw with the mouth in the open position, measured in mm. Scales were collected immediately above the lateral line approximately halfway between the gill and dorsal fin from the left side of selected Sacramento pikeminnow of different size classes (Figure 4). We analyzed scales to determine the approximate age of randomly selected Sacramento pikeminnow.

Table 1. 2006 Chorro Creek Sacramento Pikeminnow Sampling Overview

2006 Sampling Dates	Locations	Air Temp. °C (°F)	Water Temp. °C (°F)	Method	Sacramento Pikeminnow Sampled	Other Fish Observed
March 22	CRBC	--	--	Seining	0	2 bluegill
March 24	CRBC/CFRA	22 (72)	16 (61)	Hook & Line	12	1 Sacramento pikeminnow
May 1	CFRA	23 (73)	19 (66)	Hook & Line	0	0
May 12	CCER	22 (71)	21 (69)	Hook & Line	12	1 *O. mykiss*
June 5	CCER	26 (79)	22 (71)	Hook & Line	10	7 Sacramento pikeminnow 3 *O. mykiss*
June 16	CCER	--	--	Hook & Line E-Fishing	10	14 Sacramento pikeminnow 8 Sacramento sucker 3 *O. mykiss*
June 29	CFRA/CSLO	24 (75)	21 (70)	Hook & Line	10	2 Sacramento pikeminnow 14 *O. mykiss* (includes 4 young-of-the-year at HOBC[1])
Sept. 1	CFRA	19 (67)	18 (65)	Hook & Line E-Fishing	9	20 *O. mykiss* 7 Sacramento sucker 1 speckled dace 4 sculpin
Sept. 19	CRBC	20 (68)	18 (65)	Hook & Line E-Fishing	11	11 Sacramento pikeminnow 12 Sacramento sucker 1 *O. mykiss*
Oct. 27	CCER/CSLO	27 (81)	17 (63)	Hook & Line	25	5 Sacramento pikeminnow
				Totals:	99	2 bluegill 40 Sacramento pikeminnow[2] 42 *O. mykiss* 27 Sacramento sucker 1 speckled dace 4 sculpin

1 *O. mykiss* young-of-the-year observed in small, side channel (i.e., sub-optimal habitat) beneath Highway 1 Bridge.

2 Additional 40 Sacramento pikeminnow observed during sampling were <150 mm and not included as part of analysis.

CRBC = Canet Road Bridge Crossing
CFRA = Chorro Flats Restoration Area
CCER = Chorro Creek Ecological Reserve
CSLO = Camp San Luis Obispo

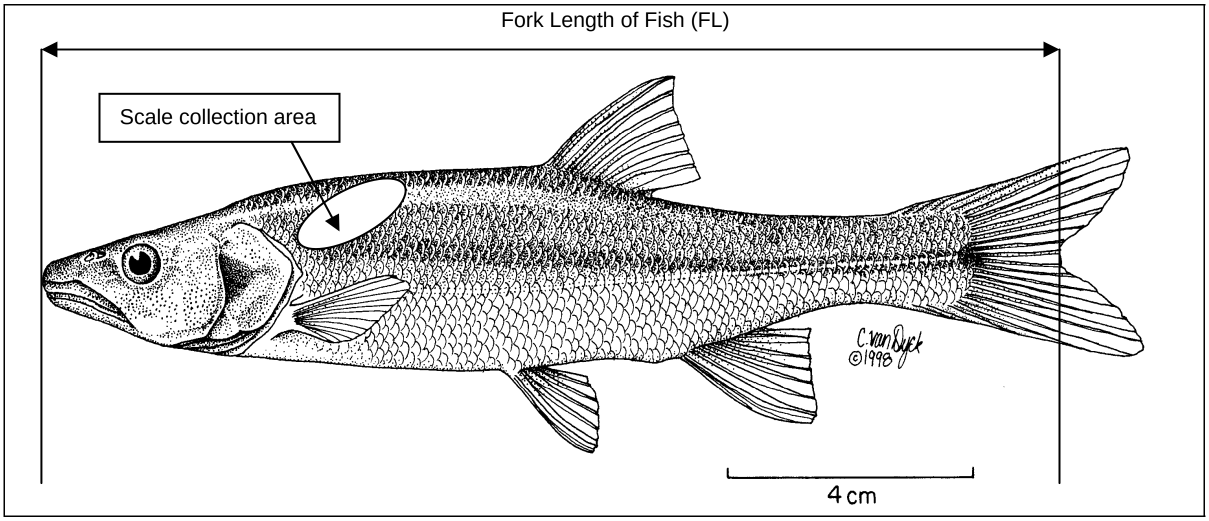


Figure 4. Illustration of Sacramento pikeminnow (Moyle 2002). Double-headed arrow indicates fork length of fish; white circle indicates portion of body where scale samples were collected from selected Sacramento pikeminnow.

All Sacramento pikeminnow were euthanized and processed on-site. Specifically, the entire digestive tract of Sacramento pikeminnow >150 mm FL were excised and preserved in 95% ethanol. Field processing of samples was typically completed within 30 minutes of capture. Processed stomach samples were returned to the laboratory for analysis. All Sacramento pikeminnow <150 mm were disposed of on-site in an attempt to prevent further proliferation of the species within Chorro Creek.

In the laboratory, prey items were extracted from the esophagus to the second turn of the S-shaped digestive tract. Prey were generally identified to species for vertebrates, family for insects, and order for other invertebrates. I developed a laboratory bench sheet which was utilized to document the percent composition and frequency of prey items from each stomach sample (Appendix B). Once identified and enumerated, I placed each prey item into a labeled glass container with 95% ethanol to be weighed later. The total tally for each prey type per stomach was used to determine percent frequency of the sample. The most problematic component of the laboratory analysis and potential for error was determining the freqency of unidentified insects. Unidentified insect heads were counted as one individual during the enumeration process. However, all other insect body parts were consolidated into a single mass which was spread evenly across the sample petri dish. I then segmented the consolidated biomass into smaller sections equal in mass (both height and width) to the average sized identifiable insect within the sample and enumerated them accordingly. Although infrequent, I repeated this method as necessary to acquire a frequency estimate for the unidentified insect category in all stomach samples. The other potenial for error enocuntered during this process was the misidentification of terrestrial versus aquatic insect parts.

Individual prey items for each stomach sample were later blotted dry and weighed to the nearest 0.01 g using a Denver Instrument Company TL-2102 scientific scale. To avoid prey weight values equaling zero and possible skewing of mean weight values, all prey items weighing less than 0.01 g were given a value of 0.005 g which represents the value between 0.01 and zero. I utilized the bench sheets again during this process to document the percent composition by weight of each prey type per stomach sample.

Chapter 4 – Data Analysis

Following the methods established by Nakamato and Harvey (2003), diet were categorized by season for further anaylsis. Specifically, February to May was defined as the “Early Season” which represents high flow periods and samples collected from June to October were defined as the “Late Season”. Prey were further divided into three broad categories: fishes, insects, and miscellaneous. The diet composition was further seperated into greater taxonomic detail by sampling location, season and Sacramento pikeminnow size (< 250 mm FL, > 250 mm FL). The overall patterns in Sacramento pikeminnow diet were analyzed using the Shannon-Weiner diversity index (H’) as a response variable, where $H' = -\Sigma p_i 1np_i$. The proportional composition of individual Sacramento pikeminnow diets (p_i’s) were calculated using both the mass and the number of individuals in each taxonomic category. H’ was analyzed using analysis of covariance (ANCOVA), with sampling location and season as main effects and Sacramento pikeminnow fork length as the covariate.

Because of its potential signficance to resource managers, the level of piscivory by Sacramento pikeminnow within Chorro Creek was analyzed in greater detail. Following the methods utlized by Nakamato and Harvey (2003), the goal was to analyze the proportion of fish (by weight) in the diet using the same ANCOVA design to evaluate diet diversity, above. Second, an attempt was made to quantify the realationship between Sacramento pikeminnow size and fish prey size using linear regression.

Due to its relation to piscivory, collected scales were assessed to determine approximate age of sampled Sacramento pikeminnow. Two types of scales ctenoid and cycloid, are most commonly used in age determination (Cailliet et al. 1986). Cycloid scales occur principally on soft-rayed fish, including Sacramento pikeminnow. Both scale types display groups of concentric rings known as circuli that can be classified into annuli and interpreted as seasonal growth marks (Cailliet et al. 1986). The circuli are formed by differential deposition of calcium carbonate and protein over time. During colder periods, growth and formation of rings typically slows, causing circuli to become crowded or incomplete. When growth resumes in spring, the new circuli grow around or cut over previously existing circuli (Devries and Frie, 1996). These “cut over” rings are known as annuli and are commonly used to denote a year’s growth (Figure 5). As part of this study, three biologists independently examined up to six collected scales per sampled Sacramento pikeminnow under a microfiche reader and enumerated the number of annuli to acquire age estimates. A consensus was then reached between the three biologists on the approximate age for each of the sampled Sacramento pikeminnow. The process of scale examination also assisted in the species identification of scales found in stomach samples.

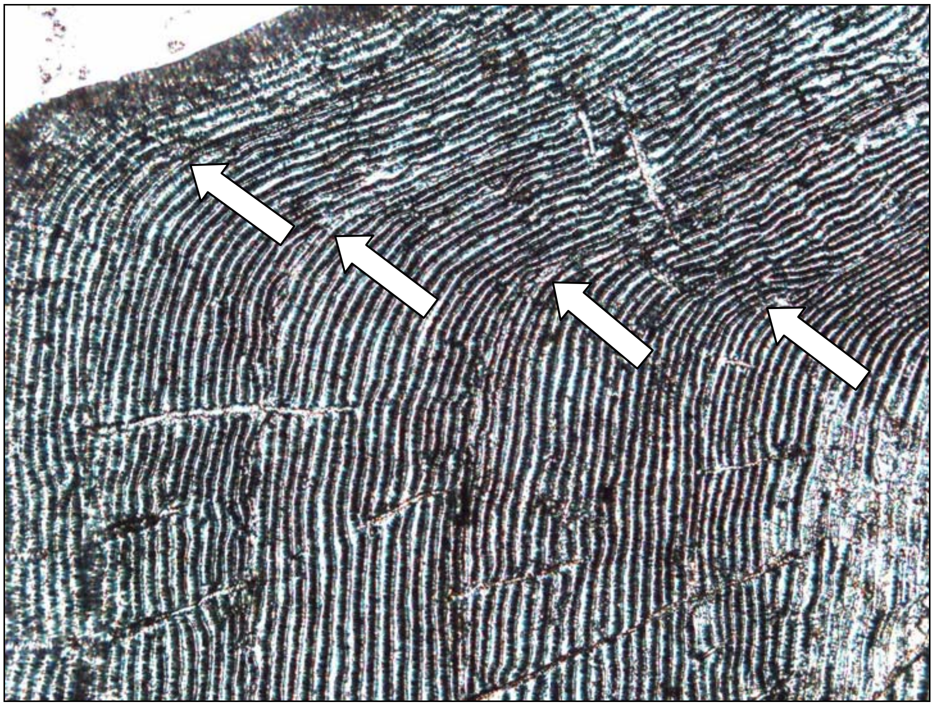


Figure 5. Partial photograph of Sacramento pikeminnow scale. White arrows indicate locations of annual growth rings (annuli) that are used to determine age of fish.

Finally, a linear regression analysis was conducted to determine if a linear relationship exists between the captured Sacramento pikeminnow fork length and weight. Fork length was established as the independent variable due to the slow growth of the fish, while weight can fluctuate depending on the amount of prey items contained in the stomach. Due to the curvilinear relationship of the length versus weight data, the natural logarithms of both length and weight were analyzed which is typical of allometric data.

The regression analysis was also conducted to determine if a linear relationship exists between pikeminnow fork length and gape and pikeminnow fork length and age, as determined by the scale analysis discussed above. As was the case when comparing length against weight, fork length was established as the independent variable. The statistical software package utilized for all analyses was MINITAB Version 15 with a significance level (P-value) of <0.05 (i.e., 95% confidence interval).

Chapter 5 - Results

Stomach contents of 99 Sacramento pikeminnow ranging from 150 to 410 mm FL were examined. Prey were identified in 88% of the samples collected in the early season and 84% of the samples collected in the late season. Sacramento pikeminnow consumed a wide variety of prey (Table 2). Fish or evidence thereof (i.e., scales) were identified in 12% of the samples collected. However, no *O. mykiss* were observed in foregut contents during this study. In general, invertebrates became less abundant and fish and other large prey items more abundant with increasing Sacramento pikeminnow size (Figure 6). Other invertebrates, especially crustaceans (i.e., crayfish) and gastropods represented the most abundant prey items in both size classes (Figures 7 and 8). When grouped by season and pikeminnow size, no prey category represented more than one-third of the diet (Table 2).

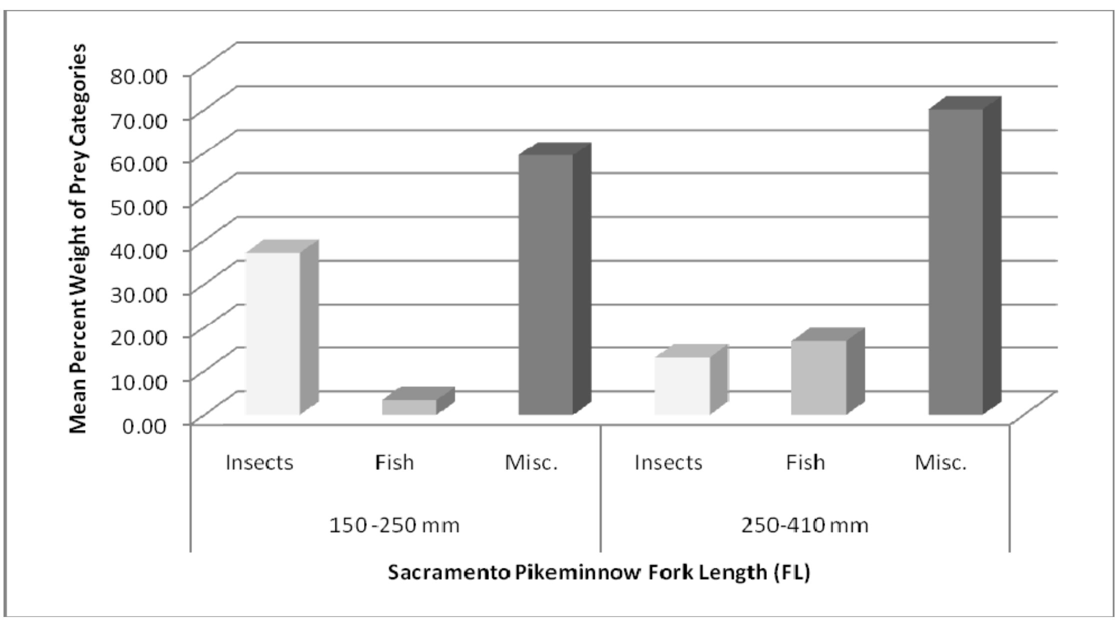


Figure 6. Mean percent weight of fish and insect prey in the diet of Sacramento pikeminnow from all sample reaches of Chorro Creek combined by predator size class. Sample sizes include only fish with food in foregut.

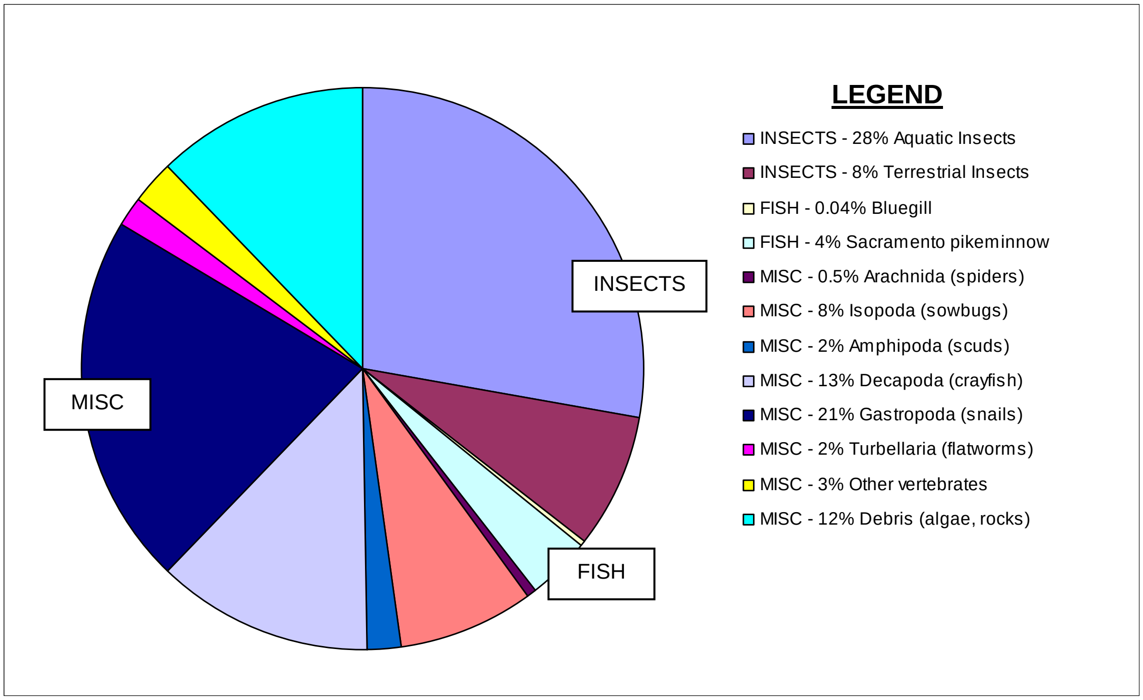


Figure 7. Mean percent weight of insect prey, fish and misc. items in the diet of Sacramento pikeminnow 150-250 mm FL from all sample reaches of Chorro Creek combined. Sample sizes include only fish with food in foregut.

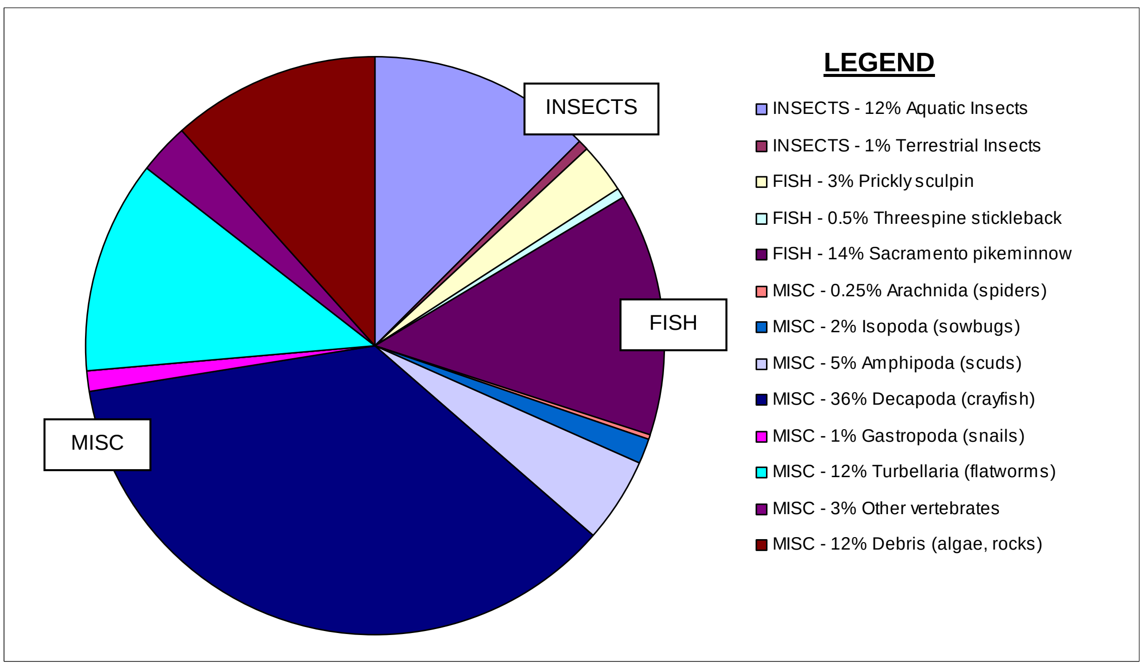


Figure 8. Mean percent weight of insect prey, fish and misc. items in the diet of Sacramento pikeminnow 250-410 mm FL from all sample reaches of Chorro Creek combined. Sample sizes include only fish with food in foregut.

Table 2. Diet of Sacramento pikeminnow collected from the main stem Chorro Creek between February and October 2006. Mean percent by wet weight and (frequency of occurrence) of prey items are presented, with Sacramento pikeminnow categorized by season and size class.

Season	**February – May (Early)**		**June – October (Late)**	
Size class (mm FL)	**< 250**	**> 250**	**< 250**	**> 250**
Number of pikeminnow	11	13	45	30
Insects				
Unidentified aquatic insects	12.84 (20.21)	0.01 (5.36)	7.08 (14.43)	2.59 (3.81)
Coleoptera (unk. family)			0.15 (1.46)	0.01 (1.61)
Chrysomelidae	0.32 (0.08)		0.02 (0.01)	0.06 (0.20)
Curculionidae				0.06 (0.20)
Dytiscidae	0.64 (0.17)	1.74 (3.85)	4.27 (1.34)	0.11 (0.12)
Elmidae			0.05 (1.06)	
Diptera (unk. family)	1.62 (0.91)			
Chironomidae	6.49 (4.60)			3.23 (3.23)
Simuliidae	9.09 (9.09)		0.05 (0.08)	0.02 (0.02)
Stratiomyidae			0.10 (0.06)	
Ephemeroptera (unk. family)		0.04 (1.42)	3.29 (3.88)	
Baetidae	4.83 (4.86)	14.29 (14.29)	0.26 (0.13)	0.28 (1.19)
Hemiptera				
Corixidae		0.01 (0.28)	1.30 (3.12)	0.10 (0.12)
Lepidoptera (unk. family)			0.41 (0.91)	
Pyraustinae	1.30 (1.30)			
Odonata (unk. family)			0.08 (0.15)	
Lestidae				0.06 (0.07)
Coenagrionidae			0.24 (0.33)	
Trichoptera (unk. family)		0.01 (0.70)	0.10 (0.11)	
Hydropsychidae	3.16 (2.27)		5.22 (7.63)	0.75 (2.85)
Unidentified terrestrial insects	0.51 (0.53)		0.01 (0.01)	0.65 (0.65)
Hymenoptera	3.67 (3.20)		7.63 (8.39)	0.11 (0.50)
Fish				
Native Fishes				
Cottus asper				3.23 (3.23)
Gasterosteus aculeatus		1.08 (0.28)		
Non-native Fishes				
Lepomis macrochirus			0.04 (0.07)	
Ptychocheilus grandis	10.26 (9.92)	7.69 (7.69)	1.14 (0.76)	12.10 (12.10)
Miscellaneous				
Arachnida	13.61 (13.03)	0.66 (2.98)	0.05 (0.03)	0.01 (0.40)
Isopoda				
Oniscidae	5.56 (5.88)	0.01 (0.70)	6.51 (4.76)	1.72 (4.90)
Amphipoda			1.94 (1.88)	5.43 (6.54)
Decapoda				
Pacifastacus leniusculus	1.01 (0.53)	28.38 (16.37)	11.03 (4.87)	28.61 (15.97)
Gastropoda				
Physa sp.	0.83 (0.62)	1.18 (3.95)	22.28 (21.13)	0.86 (1.20)
Gyraulus sp.			0.11 (0.14)	

Table 2 (Continued). Diet of Sacramento pikeminnow collected from the main stem Chorro Creek between February and October 2006. Mean percent by wet weight and (frequency of occurrence) of prey items are presented, with Sacramento pikeminnow categorized by season and size class.

Season	February – May (Early)		June – October (Late)	
Size class (mm FL)	**< 250**	**> 250**	**< 250**	**> 250**
Number of pikeminnow	11	13	45	30
Miscellaneous (Continued)				
Oligochaeta				0.05 (0.22)
Turbellaria	9.56 (8.54)	22.46 (22.46)	0.71 (0.45)	4.03 (4.03)
Reptilia				
Elgaria multicarinata			2.25 (0.76)	
Mammalia				
Unidentified mammal			0.30 (0.28)	
Microtus californicus				3.23 (4.84)
Debris (e.g., algae, rock, and wood fragments)	5.63 (5.16)	7.05 (4.28)	11.9 (10.39)	10.13 (9.44)

During the early season, unidentified aquatic insects (13%), dipterans (16%), and Sacramento pikeminnow (10%) dominated the stomach contents of small (<250 mm FL) Sacramento pikeminnow. Arachnids (14%) and turbellaria of the family Planariidae (i.e., planaria) (10%) were also identified as the only prey items within otherwise empty stomachs in the early season. During the late season, a large portion of the diet of small Sacramento pikeminnow consisted of gastropods, particularly *Physa* sp. (22%), crayfish (11%), terrestrial insects of the order hymenoptera (8%), isopods of the family Oniscidae (7%), and unidentified aquatic insects (7%). In addition, clumps of algae, rock, and woody debris were also prominent in the stomachs of small Sacramento pikeminnow during the late season (12%).

During the early season, crayfish (28%), mayflies of the family Baetidae (14%), and Sacramento pikeminnow (8%) comprised the majority of the diet of large Sacramento pikeminnow (>250 mm FL) with planaria (22%) typically representing the dominant contents of otherwise empty stomachs. In the late season, crayfish (29%), Sacramento pikeminnow (12%), and debris (e.g., algae, rock, wood fragments, etc.) (10%) formed the largest part of the diet of large Sacramento pikeminnow.

Individual Shannon-Weiner diversity indexes based upon the mass of prey varied significantly between Sacramento pikeminnow greater than or less than 250 mm FL ($F_{1,79}$ = 5.34, p = 0.023) and were only marginally significant between reaches (Upper versus Lower Chorro Creek) ($F_{1,79}$ = 3.04, p = 0.085) (Table 3, Appendix C). Individual Shannon-Weiner diversity indexes were significantly higher in lower Chorro Creek compared to upper Chorro Creek during both the late and early seasons (Table 3, Appendix C). The season ($F_{1,79}$ = 0.05, p = 0.82) and stream reach (Upper versus Lower Chorro Creek) x season interaction ($F_{1,79}$ = 0.12, p = 0.73) were not significant terms in the analysis of covariance for Sacramento pikeminnow stomach content items. Results may be skewed by a noticeable sample bias in upper Chorro Creek from early season to late season due to constraints of hook-and-line sampling (i.e., n=10 vs. n=46, Table 3).

Table 3. Mean (SE) Shannon-Weiner individual diet diversity by size class for Sacramento pikeminnow collected from within upper and lower Chorro Creek. Sample sizes include only fish with food in foregut.

Lower Chorro Creek				
	March-May		**June-October**	
Size Class (FL)	**n**	**Diversity (weight)(frequency)**	**n**	**Diversity (weight)(frequency)**
150-250 mm	4	(0.42) (0.42)	9	(0.43) (0.44)
>250 mm	7	(0.20) (0.27)	8	(0.18) (0.31)
Upper Chorro Creek				
	March-May		**June-October**	
Size Class (FL)	**n**	**Diversity (weight)(frequency)**	**n**	**Diversity (weight)(frequency)**
150-250 mm	6	(0.36) (0.31)	30	(0.19) (0.30)
>250 mm	4	(0.00) (0.17)	16	(0.17) (0.23)

The stomach content analysis did not result in the identification of a sufficient amount of fish prey items to confidently determine if the proportion of fish in the diet exhibited different temporal trends in upper and lower Chorro Creek using ANCOVA. However, a summary of the fish prey items identified in the Sacramento pikeminnow foregut samples is provided in Table 4. Additionally, Figures 2 and 3 provide an overview of where the various fish prey items were identified during sampling.

The scale age analysis included nine Sacramento pikeminnow collected during the 2006 sampling season (Figure 9) and an additional 13 Sacramento pikeminnow collected in 2008 from both upper and lower Chorro Creek. Age estimates of Sacramento pikeminnow collected during these sampling periods ranged from 1 to 6 years, with an average age of 3. The linear regression equation using the fork length and age data yielded an r^2 value of 81.7% (P-value <0.001), indicating that a relatively strong linear relationship exists between these two variables (Appendix C). A fitted line plot was also developed to illustrate the linear relationship between the Sacramento pikeminnow fork length and age and includes 95% confidence intervals and 95% prediction intervals (Figure 10).

Table 4. Sacramento Pikeminnow Predator and Fish Prey Summary

Sacramento Pikeminnow Length (FL [mm])	Location Captured	Season Captured	Fish Prey & Length (FL [mm])	Fish Prey Condition	Ratio of Prey to Predator Length
289	Chorro Flats Restoration Area – Lower	Feb-May (Early)	Threespine stickleback (46 mm)	Entire	.16
329	Chorro Flats Restoration Area – Lower	Feb-May (Early)	Sacramento pikeminnow (±191 mm[1])	Remnant Scales	.58
233	Chorro Creek Ecological Reserve - Upper	Feb-May (Early)	Sacramento pikeminnow (unknown[2])	Remnant Scales	Unknown
242	Chorro Creek Ecological Reserve - Upper	Feb-May (Early)	Sacramento pikeminnow (unknown[2])	Remnant Scales	Unknown
324	Chorro Creek Ecological Reserve - Upper	June-Oct (Late)	Sacramento pikeminnow (±118 mm[1])	Remnant Scales	.36
306	Chorro Creek Ecological Reserve - Upper	June-Oct (Late)	Sacramento pikeminnow (±118 mm[1])	Remnant Scales	.36
218	Camp San Luis Obispo -Upper	June-Oct (Late)	Bluegill (unknown[3])	Remnant Scales	Unknown
410	Chorro Flats Restoration Area - Lower	June-Oct (Late)	Prickly sculpin (±130 mm)	Partially digested	.32
235	Canet Road - Lower	June-Oct (Late)	Sacramento pikeminnow (unknown[2])	Remnant Scales	Unknown
277	Camp San Luis Obispo – Upper	June-Oct (Late)	Sacramento pikeminnow (±118 mm[1])	Remnant Scales	.36
251	Chorro Creek Ecological Reserve - Upper	June-Oct (Late)	Sacramento pikeminnow (unknown[2])	Remnant Scales	Unknown
273	Chorro Creek Ecological Reserve - Upper	June-Oct (Late)	Sacramento pikeminnow (unknown[2])	Remnant Scales	Unknown

[1] Values based on 1- and 2-yr-old scales using inverse prediction with the fitted line plot equation established for Sacramento pikeminnow age versus fork length (Age = - 0.6235 + 0.01372 SPM Length (FL)).

[2] Age of Sacramento pikeminnow scale undetermined due to scale damage and/or indistinct annuli.

[3] Bluegill scale age estimates not included as part of this analysis.

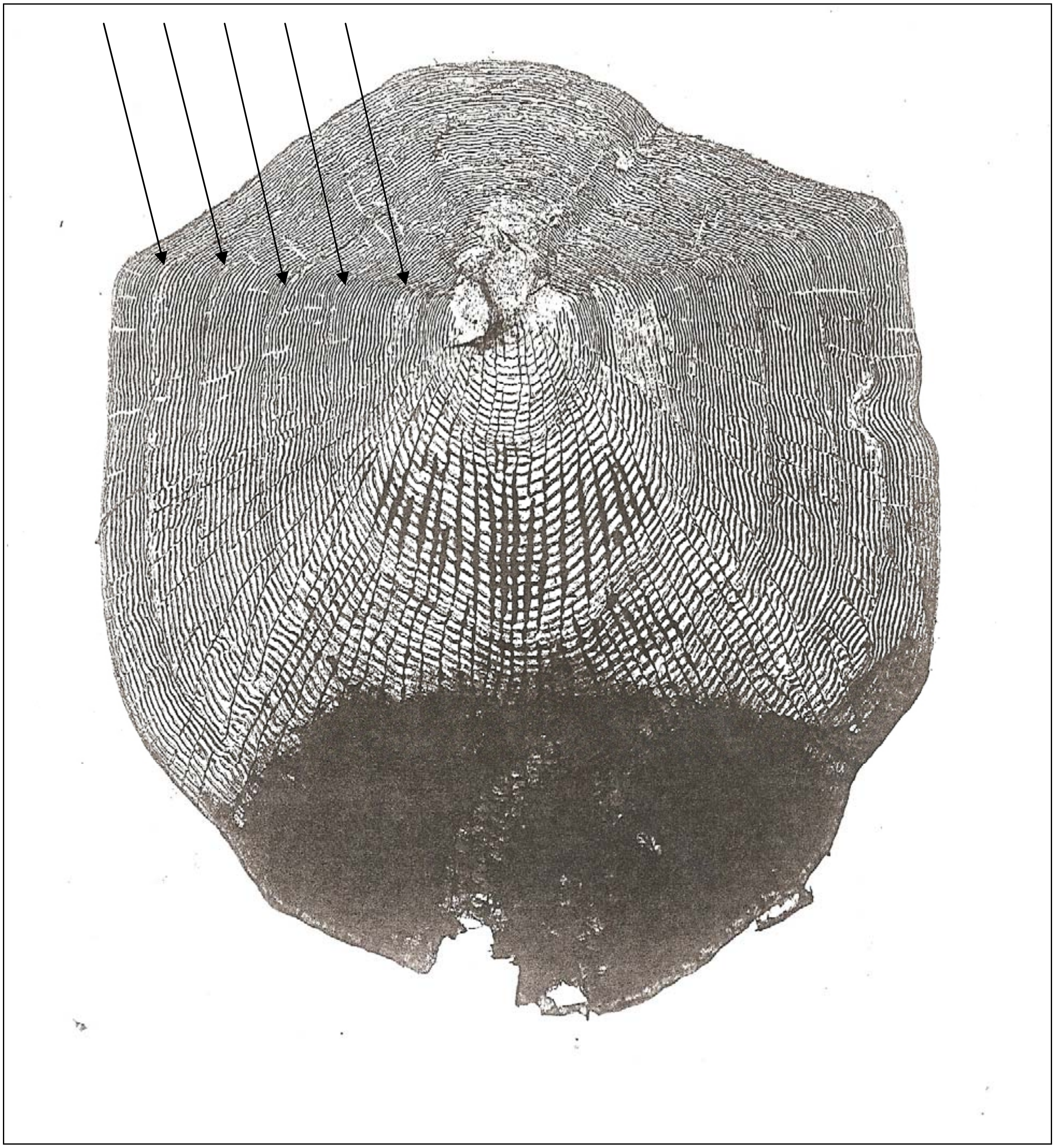


Figure 9. This scale was collected from Sacramento pikeminnow sample #55 within upper Chorro Creek (FL = 350 mm). Notice each arrow represents one year of growth and is characterized where the annulus are broken and new rings begin (age estimate = 5 yrs.).

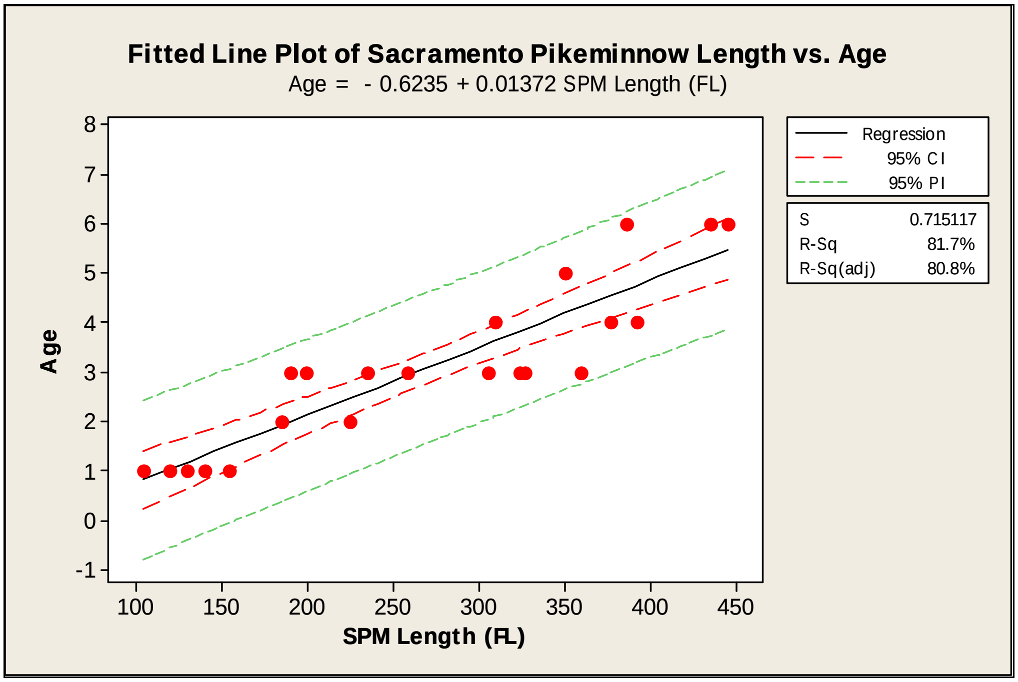


Figure 10. Fitted line plot and regression equation for Sacramento pikeminnow fork length versus age. Includes scales from Sacramento pikeminnow captured during 2006 and 2008 sampling events within upper and lower Chorro Creek.

The stomach content analysis did not result in the identification of a sufficient amount of fish prey items to confidently characterize the linear relationship between the lengths of Sacramento pikeminnow predators and their prey. Overall, only 12% of the stomach samples contained either fish prey or evidence thereof in the form of scales. Entire fish prey identified included one threespine stickleback (Figure 11) and one prickly sculpin and scale identification included one bluegill and numerous Sacramento pikeminnow (Table 4, Figures 2 and 3).

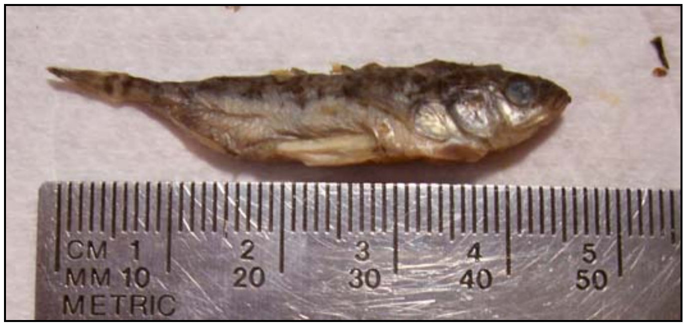


Figure 11. Photograph of well preserved threespine stickleback (*Gasterosteus aculeatus*).

Based on further Sacramento pikeminnow scale analysis utilizing the age estimate methods outlined above, Sacramento pikeminnow prey were determined to be between one and two years of age. Utilizing "inverse prediction" of the linear regression model and fitted line plot equation established for Sacramento pikeminnow fork length versus age (Age = - 0.6235 + 0.01372 SPM Length) (FL) (Figure 10), the Sacramento pikeminnow fork length for 1-year-old fish was estimated at 118 mm (4.6 in) and fork length for 2-year-old fish was estimated at 191 mm (7.5 in) (Table 4).

A summary of the fish prey items retrieved from Sacramento pikeminnow foreguts during the 2006 sampling event and their approximate lengths is provided in Table 4. Piscivorous Sacramento pikeminnow averaged 282 mm (11 in) FL (range 218-410 mm [8.6-16 in] FL) while prey fishes averaged 120 mm (4.7 in) FL (range 46-191 mm [1.8-7.5 in] FL). The ratio of fish prey to predator length ranged 0.16-0.58 (Table 4).

The regression equation using the natural logarithm fork length and natural logarithm weight data yielded an r^2 value of 98.8% (P-value <0.001, Figure 12, Appendix C). Furthermore, the regression equation using the fork length and gape data yielded an r^2 value of 77.8% (P-value <0.001, Figure 13, Appendix C).

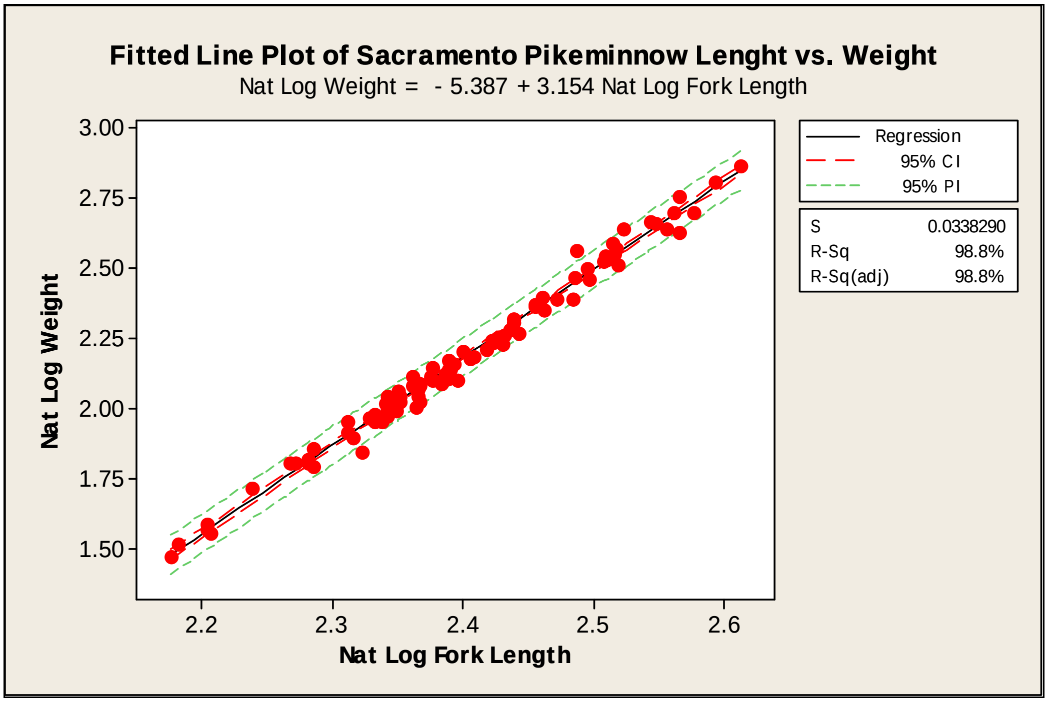


Figure12. Fitted line plot and regression equation for natural logarithms of Sacramento pikeminnow fork length versus weight.

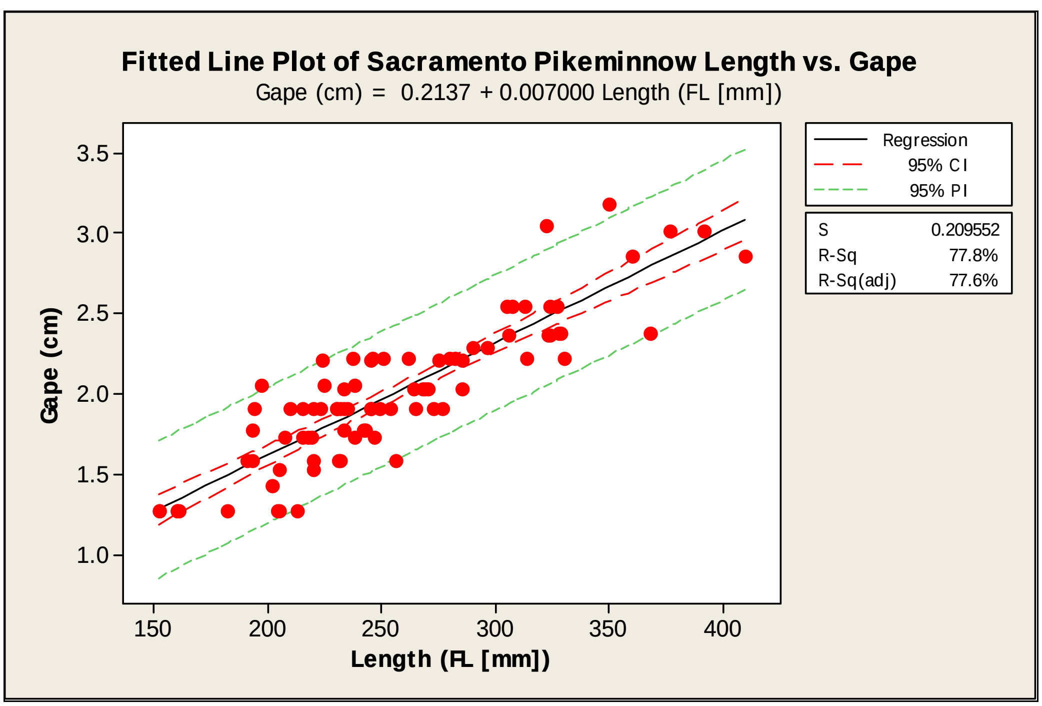


Figure 13. Fitted line plot and regression equation for Sacramento pikeminnow fork length versus gape.

Chapter 6 – Discussion

I acknowledge that the constraints of site access coupled with hook-and-line sampling has led to some sample bias which limits my ability to generalize about the overall affects of Sacramento pikeminnow piscivory throughout the Chorro Creek watershed. Despite these limitations, this study did provide some insight on the feeding habits of Sacramento pikeminnow within the main stem of Chorro Creek which have management implications for future studies and *O. mykiss* restoration projects.

The overall diet patterns of Sacramento pikeminnow sampled in this study parallel previous findings from the Eel River and elsewhere, with the exception of a tendency toward cannibalism. Specifically, past research also documented an overall increase in piscivory with predator body size; although fish were more prevalent in the diets of Sacramento pikeminnow in those studies (Brown 1990; Brown and Moyle 1997; Nakamoto and Harvey 2003; Nobriga and Feyrer 2007). Further, observations from this and previous studies also indicate that the Sacramento pikeminnow is a generalist predator with a highly variable diet (Nakamoto and Harvey 2003, Nobriga and Feyrer 2007). Although this study did not include a focused prey electivity analysis, the results add the observation of a tendency toward Sacramento pikeminnow cannibalism and increased consumption of planaria within degraded stream reaches with limited prey availability (i.e., upper Chorro Creek). Similar to a study in the Sacramento Delta (Nobriga and Feyrer 2007); no salmonids were observed in foregut contents during this study due to the apparent availability of other prey items.

6.1 Diet Analysis

As documented in the Eel River and Sacramento Delta (Nakamoto and Harvey 2003, Nobriga and Feyrer 2007), this study observed a difference in diet diversity both seasonally and spatially, with Sacramento pikeminnow within lower Chorro Creek having the highest diet diversity in both the early and late seasons (Table 3). Seasonal fluctuations probably reflects differences in prey availability within Chorro Creek from periods of high flows and flooded riparian zones to low flow conditions. The higher diet diversity within lower Chorro Creek is most likely attributable to the increased quality of in-stream habitat within the CFRA and associated availability of multiple prey types (e.g., benthic macroinvertebrates, native fishes [threespine stickleback, sculpin], and crayfish).

Despite previous findings that Sacramento pikeminnow do not forage selectively (Nakamoto and Harvey 2003), they may negatively influence the abundances of some native fish species. For example, White and Harvey (2001) documented lower densities of sculpin in the Eel River when compared to two other drainages due to the presence of Sacramento pikeminnow and Brown and Moyle (1997) suggested that predation by Sacramento pikeminnow may affect the distribution and abundance of threespine stickleback in the Eel River. Specifically, White and Harvey (2001) determined that introduced pikeminnow render pools uninhabitable for native sculpin forcing a shift from pools to riffles. Further, prickly sculpin make downstream spawning migrations in late winter (January-February) and stickleback typically migrate in spring (Moyle 2002). Thus, Sacramento pikeminnow predation may have a greater impact on sculpin and stickleback during periods of downstream spawning migrations when these native fish are forced to move through pools containing large pikeminnow. Native fish predation may also be exasperated by the fact that large (>350 mm [13.8 in] FL), radio-tagged pikeminnow in the Eel River have been documented moving from pools to riffles at night presumably in search of prey (Harvey and Nakamoto 1999). Further, pikeminnow large enough to consume sculpin have been observed actively foraging in riffles of the Eel River during the day (White and Harvey 2001). Reduction in population densities of prickly sculpin may also have indirect ecosystem-level consequences as sculpin larvae serve as potential food source for many organisms, including juvenile salmonids (Heard 1965).

The native California red-legged frog (*Rana aurora draytonii*) may also be significantly affected by the Sacramento pikeminnow due to concentrated predation in areas where frogs represent readily available prey. California red-legged frog populations are known to occur within Camp San Luis Obispo (upper Chorro Creek) where Sacramento pikeminnow have been observed in relatively dense numbers. Adult California red-legged frogs typically breed from late Nov-April along the margins of slow moving streams with dense riparian or emergent vegetation (Stebbins 2003, Hayes and Jennings 1988). Therefore, breeding season and the subsequent larval development period into the early summer months represents the period when adult California red-legged frogas and larvae may be particularly susceptible to increased predation by Sacramento pikeminnow.

Within the Eel River, the only selective feeding by Sacramento pikeminnow was the apparent avoidance of cannibalism even though small Sacramento pikeminnow were observed in association with other prey items year round (Nakamoto and Harvey 2003).

However, cannibalistic behavior among Sacramento pikeminnow was observed during this study; approximately 75% of the fish prey identified in the sample foreguts was comprised of Sacramento pikeminnow averaging one-year in age (Table 4). The majority of the cannibalistic behavior occurred within the CCER downstream of the CMC Wastewater Treatment Plant (Figure 7) where apparent degraded water quality conditions and increased water temperatures have allowed Sacramento pikeminnow populations to proliferate at this location. The degraded water quality conditions have also resulted in low macroinvertebrate species richness (<25 taxon) as documented by rapid bioassessment sampling at the CCER (Morro Bay National Estuary Program 2008). The evidence of cannibalism appeared to increase in the late season which coincides with apparent decreased water levels, limited prey availability within pool habitat areas, and appearance of young-of-the-year pikeminnow. To determine the significance of cannibalism on Sacramento pikeminnow population size and recruitment dynamics, further focused analysis would be required on prey electivity within Chorro Creek.

Several factors probably contributed to the lack of *O. mykiss* observations in the diet assemblage of Sacramento pikeminnow sampled during this study. First, sample locations were selected based on available access routes and landowner consent including the California Department of Fish and Game. Due to the lack of current Sacramento pikeminnow and *O. mykiss* population data, high risk areas for *O. mykiss* predation were unknown and unable to be incorporated into the sampling site selection process. In the Eel River, high rates of consumption of salmonids by Sacramento pikeminnow were documented at sites where salmonids were aggregated in relatively high densities (Nakamoto and Harvey 2003). Although, *O. mykiss* were observed and incidentally captured during the 2006 sampling event(s), Sacramento pikeminnow outnumbered *O. mykiss* approximately 3:1 (Table 1). Thus, a relatively low abundance of *O. mykiss* at sample locations during the 2006 sampling event(s) may have been the primary factor for lack of *O. mykiss* observations in pikeminnow stomachs.

Second, there was an apparent tendency for Sacramento pikeminnow to favor crayfish (28% of diet of Sacramento pikeminnow >250 mm FL) and other benthic organisms, such as freshwater snails during this study (22% of the diet of Sacramento pikeminnow <250 mm FL in the late season). The degraded stream conditions have allowed a proliferation of non-native crustaceans and benthic organisms within the main stem of Chorro Creek. Although no abundance estimates are available, crayfish were identified in all sample reaches during the surveys and were considered a readily available prey item for both large and small pikeminnow. Further, poor water quality conditions such as those occurring in the main stem of Chorro Creek are conducive to the proliferation of non-insect, benthic organisms such as freshwater snails which are tolerant of impaired water quality conditions (CDFG 2009). Foraging pikeminnow within Chorro Creek are also expected to exert less energy preying upon crayfish versus fish which are typically more evasive. Thus, crayfish represent a readily available, low risk/high reward prey item for foraging pikeminnow throughout the main stem of Chorro Creek.

Third, piscivory is primarily a visual activity which can be affected by turbid conditions. Specifically, during periods of high flow events and increased turbidity, Sacramento pikeminnow would be expected to hold near the stream bottom which may influence the consumption of benthic prey as discussed above (e.g., crayfish, freshwater snails, and sculpin). Nakamoto and Harvey (2003) also considered turbidity a major factor in the tendency toward Sacramento pikeminnow to select benthic prey in the Eel River. In summary, the overall results of this study support the conclusion that Sacramento pikeminnow are not significant predators of salmonids in natural stream conditions (Brown and Moyle 1981, Nakamoto and Harvey 2003, Nobriga and Feyrer 2007).

However, in contrast to the overall results of this study, 2008 Sacramento pikeminnow control efforts within Chorro Creek resulted in the identification of *O. mykiss* in the foregut of five captured Sacramento pikeminnow. Other native fish observed in the foregut of captured Sacramento pikeminnow during these efforts included, prickly and staghorn sculpin, threespine stickleback and speckled dace. Evidence of cannibalism was also observed during this period (F. Otte, pers. comm.). The Sacramento pikeminnow removal efforts involved systematically electro-fishing approximately 12.9 km (8 mi) of Chorro Creek which resulted in identification of 1,548 *O. mykiss* and the removal of 932 Sacramento pikeminnow. In general, *O. mykiss* were most abundant in the lower portions of Chorro Creek, with the highest densities encountered at the confluence of Chorro Creek and San Luisito Creek down to the Morro Bay Estuary (Morro Bay National Estuary Program and HydroTerra 2009). A recent aquatic habitat and fish population assessment of San Luisito Creek concluded that this Chorro Creek tributary contains high quality habitat for *O. mykiss* (Payne and Associates 2007). Sacramento pikeminnow containing *O. mykiss* as prey during the 2008 removal efforts were limited to the Chorro Flats Restoration Area and the Chorro Creek Ecological Reserve. These 2008 observations support the conclusion that stream reaches with thermal regimes and physical habitat that allow occupation by both large

Sacramento pikeminnow and *O. mykiss* are "likely" hotspots for predation by the former (Nakamoto and Harvey 2003).

6.2 Length, Age, Weight, and Gape Relationships

Although not directly associated with the pikeminnow diet analysis, the following provides a discussion of the potential uses of the length, weight, gape and age relationship data for pikeminnow captured within Chorro Creek.

By entering a value for the fork length into equation "Age = -0.6235 + 0.01372 SPM Length (FL)", resource managers could predict the age of a fish for any given fork length within the range of values used in this study. For example, a pikeminnow with a 250 mm FL would have an estimated age of 2.8 years. However, the 95% prediction interval for this estimate is $1.279 < \beta_1 < 4.332$ (i.e., +/- 1.5 years) and, as such age estimates from this data should be used with discretion (Appendix C). Further note that this equation is based solely on Sacramento pikeminnow from the main stem of Chorro Creek ranging in fork length from 105 mm to 445 mm. Attempting to extrapolate these data and predict ages for fish outside of this range is not recommended, as small errors in the regression line are magnified and increase with the degree of extrapolation, potentially resulting in inaccurate age predictions. It is anticipated that the precision of this linear equation would strengthen over time as additional age versus length data is added to the database.

By entering a value for the fork length into equation "Nat Log Weight = - 5.387 + 3.154 Nat Log Fork Length" and "Gape (cm) = 0.2137 + 0.007000 Length (FL [mm])", respectively, resource managers could predict the weight and gape of a fish for any given fork length within the range of values used in this study with weight predictions being the most reliable due to the lack of any substantial variation due to random error (i.e., only

1.2 percent). Due to the natural logarithm, all final weight values should be raised by a power of 10. Again, these equations are based solely on Sacramento pikeminnow from the main stem of Chorro Creek ranging in fork length from 150 mm to 410 mm. Attempting to extrapolate this data and predict weight and gape for fish outside of this range is not recommended due to the magnification of small errors in the regression line which could potentially result in inaccurate weight and gape predictions. It is also anticipated that the precision of these linear equations would strengthen overtime as additional weight and gape versus length data is added to the database.

6.3 Management Implications

The low numbers of *O. mykiss* encountered during this study (Table 1) coupled with the absence of a reliable Sacramento pikeminnow population estimate preclude conclusions about the ability of Sacramento pikeminnow to influence *O. mykiss* abundance within the Chorro Creek watershed. However, the documented variability in diet and lack of prey selectivity (Nakamoto and Harvey 2003) suggests that per predator consumption of *O. mykiss* by Sacramento pikeminnow would increase approximately linearly with the abundance of *O. mykiss*. The relationship between body size and salmonid consumption for Sacramento pikeminnow (Nakamoto and Harvey 2003) and for the northern pikeminnow in the Columbia River (Peterson 2001) suggests that continued predator control should focus on large individuals. Scale analysis conducted as part of this study indicates Sacramento pikeminnow within the main stem of Chorro Creek average 3 years in age and approximately 255 mm FL, which is the period of transition into sexually maturity (i.e., end of their third or fourth year at 220-255 mm) (Moyle 2002).

To fully understand the effects of Sacramento pikemnnow predation on *O. mykiss* population dynamics within the Chorro Creek watershed, further foregut analysis is recommended. The diet analysis should be coordinated with continued Sacramento pikeminnow removal efforts in 2009 and focused on predominantly piscivorous Sacramento pikeminnow >200 mm FL (Moyle 2002, Harvey and Nakamoto 2003, Nobriga and Feyrer 2007) in stream reaches where *O. mykiss* are determined to be most abundant (i.e., Chorro Flats Restoration Area) based upon the 2008 population census data. Field methods should remain consistent with this study with the following exceptions and additions:

1. All sampling efforts should be completed via electro-fishing to ensure identification and abundance of all fish species within sampled reaches.
2. Laboratory methods should be modified to primarily focus on identification of macro-prey items (e.g., fish, crayfish, other vertebrates [frogs, rodents, etc.]) with emphasis on fish prey to reduce costs associated with extraneous laboratory analysis of benthic macroinvertebrates, terrestrial insects, and other miscellaneous items in foreguts.
3. The field methods should include a focused prey electivity analysis following the methods established by Nakamoto and Harvey (2003) to quantify the degree of selection by Sacramento pikeminnow for specific fishes or alternate prey items.
4. Telemetry studies should be completed in conjunction with the analysis above to document Sacramento pikeminnow movement within the Chorro Creek watershed including potential use of tributaries for the purposes of

spawning and extent and locations of night foraging movements as documented in the Eel River (Harvey and Nakamoto 1999).

5. Lastly, *O. mykiss* and Sacramento pikeminnow population census data should continue to be collected to determine status of *O. mykiss* population in relation to pikeminnow and potential habitat preferences within Chorro Creek of each respective species with emphasis on water temperature and flow regimes. Past analysis of Sacramento pikeminnow and *O. mykiss* habitat requirements and temperature preferences suggest that although pikeminnow are tolerant of a wider range of temperatures (4-35°C [39-95°F]), they are still subject to in-stream temperature restrictions with a tendency to avoid cooler waters (Bettelheim 2001).

As part of Task 5 (above) index reaches could also be developed to further quantify the effects of Sacramento pikeminnow removal efforts on recolonizing *O. mykiss*. Specifically, several index reaches could be established within upper and lower Chorro Creek and investigated annually to determine diversity and quantity of fishes over time. The habitat would be typed and recorded (e.g., escape cover, pool dimensions, substrate, canopy, etc.). With the primary emphasis of the Sacramento pikeminnow removal project targeting large individuals, there should be an immediate reduction in predation on *O. mykiss* coupled with an increase in available habitat through direct reduction in non-native fishes (Sacramento pikeminnow and Sacramento sucker, both species were removed from habitat traditionally utilized by *O. mykiss* in 2008). All future sampling efforts and habitat analysis should also continue to utilize and update, as necessary, the Chorro Creek Sacramento pikeminnow population data provided in this study (e.g., age, length, weight, and gape estimates).

These continued analyses coupled with the data obtained during this study will allow researchers to determine the influence of Sacramento pikeminnow on *O. mykiss* abundance within the Chorro Creek watershed. Most importantly, knowledge of the effects of Sacramento pikeminnow predation on *O. mykiss* population dynamics within Chorro Creek will allow resource managers to make informed decisions on future funding allocation and project prioritization including, but not limited to the following:

- Continued habitat improvements throughout the Chorro Creek watershed through implementation of focused site restoration projects with emphasis on improving the overall continuity, value and function of the existing riparian corridor and bordering upland habitat areas (i.e., Chorro Creek Ecological Reserve: Long Term Restoration and Management Plan);
- Removal of migration barriers to several key tributaries which are considered major limiting factors to the recovery of *O. mykiss* populations in the Chorro Creek watershed;
- Evaluation of the potential long-term effects of installing cooling towers at the CMC Wastewater Treatment Plant to lower the temperature of effluent prior to discharge to Chorro Creek due to the direct correlation between pikeminnow population numbers with increased water temperatures immediately downstream of the treatment plant outfall; and,
- Introduction of *O. mykiss* from the tributaries above Chorro Reservoir as refugia fish into a conservation hatchery where they can be reared,

spawned, and distributed back into Chorro Creek as an augmentation strategy for the current anadromous *O. mykiss* population. Genetic analysis would need to be completed prior to release into Chorro Creek to ensure no negative genetic interaction would occur.

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APPENDIX A

Site Photographs

Photo 1. Upper Chorro Creek (CSLO) - View upstream of Sampling Site beneath Highway 1 Bridge crossing.

Photo 2. Upper Chorro Creek (CSLO) - View downstream of Sampling Site beneath Highway 1 Bridge crossing.

Photo 3. Upper Chorro Creek (CSLO) –Sacramento pikeminnow sampled beneath Highway 1 Bridge crossing (June 29, 2006).

Photo 4. Upper Chorro Creek (CCER) –View downstream of Chorro Creek Ecological Reserve Sample Site.

Photo 5. Upper Chorro Creek (CCER) –View upstream of Chorro Creek Ecological Reserve Sample Site.

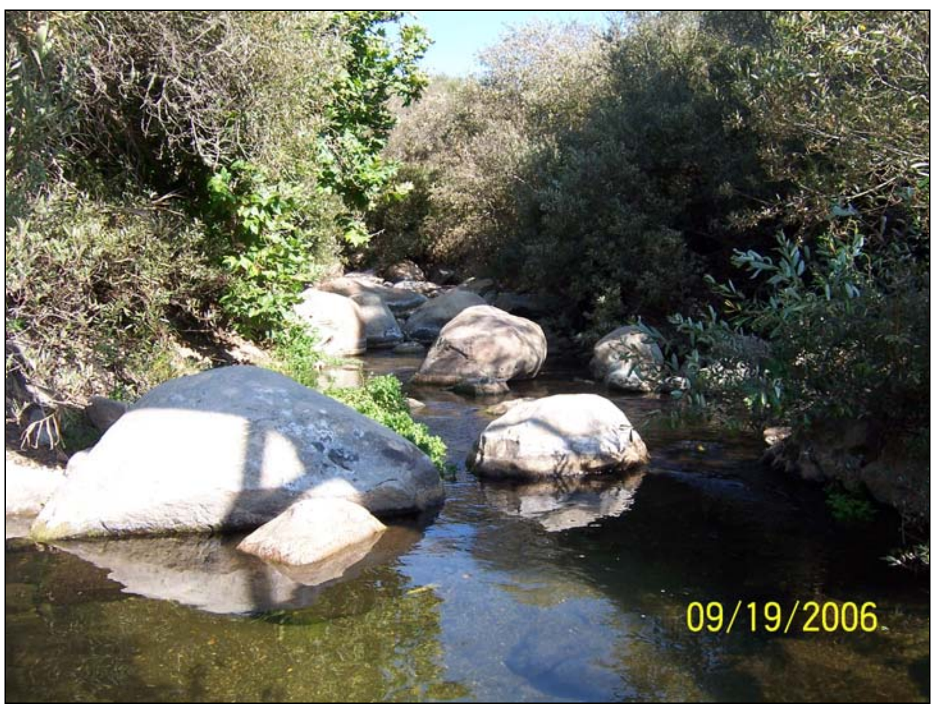


Photo 6. Lower Chorro Creek (CRBC) – View upstream of the Canet Road Bridge Crossing Sample Site.

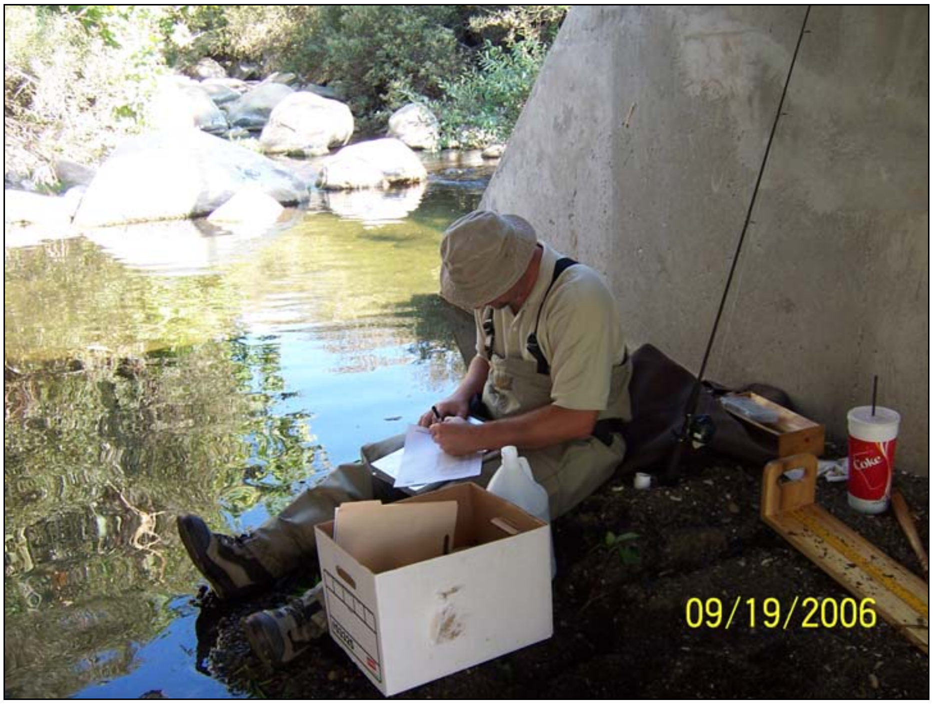


Photo 7. Lower Chorro Creek (CRBC) – Data collection and sample processing at the Canet Road Bridge Crossing Sample Site.

Photo 8. Lower Chorro Creek (CFRA) - Sacramento pikeminnow being processed by CDFG staff at the Chorro Flats Restoration Area (March 25, 2006).

Photo 9. Lower Chorro Creek (CFRA) – *O. mykiss* encountered during sampling by CDFG staff at the Chorro Flats Restoration Area (March 25, 2006).

Photo 10. Lower Chorro Creek (CFRA) - Sacramento pikeminnow sampled at the Chorro Flats Restoration Area (September 1, 2006).

APPENDIX B

Laboratory Bench Sheet

Chorro Creek Sacramento Pikeminnow Removal Project Gut Content Analysis - Laboratory Data Sheet		
Sample #:	Stream Reach:	Taxonomist(s):
Date(s) and hours worked:		

Invertebrates				
CLASS/order	**Family**	**Genus/species**	**Number (marks)**	**No.**
INSECTA				
Ephemeroptera	Baetidae			
Plecoptera				
Trichoptera				
Coleoptera	Elmidae			
	Dytiscidae			
Diptera	Chironomidae			
Hemiptera				
Odonata				
CRUSTACEA		*Cambarus* sp.		
Others				

Vertebrates				
CLASS/order	**Family**	**Genus/species**	**Number (marks)**	**No.**
SARCOPTERYGII				
	Poecilidae	*Gambusia affinis*		
	Cottidae	*Cottus asper*		
	Gobiidae	*Eucyclogobius newberryi*		
	Cetrarchidae	*Micropterus salmoides*		
		Lepomis macrochirus		
		Lepomis cyanellus		
	Catostomidae	*Catostomus* sp.		
	Cyprinidae	*Gila orcutti*		
		Rhinichthys osculus		
		Ptychocheilus grandis		
	Salmonidae	*Oncorhynchus mykiss*		
	Others			
AMPHIBIA				
	Hylidae	*Hyla regilla*		
	Ranidae	*Rana aurora draytonii*		
		Rana catesbeiana		
	Others			
Totals (#)				

APPENDIX C

Minitab Statistical Data Sheets

——— 9/22/2008 10:26:49 AM ———————————

9/26/2008 3:43:00 PM

Welcome to Minitab, press F1 for help.
Retrieving project from file: 'I:\SWD ANCOVA 092208.MPJ'

General Linear Model: SWD (Wt.) versus FL (+/- 250 mm), Reach, Season

Factor	Type	Levels	Values
FL (+/- 250 mm)	fixed	2	Greater, Less
Reach	fixed	2	Lower, Upper
Season	fixed	2	Early, Late

Analysis of Variance for SWD (Wt.), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
FL (+/- 250 mm)	1	0.26268	0.35997	0.35997	5.34	0.023
Reach	1	0.31822	0.20461	0.20461	3.04	0.085
Season	1	0.00480	0.00352	0.00352	0.05	0.820
Reach*Season	1	0.00800	0.00800	0.00800	0.12	0.731
Error	79	5.32546	5.32546	0.06741		
Total	83	5.91916				

S = 0.259636   R-Sq = 10.03%   R-Sq(adj) = 5.47%

Unusual Observations for SWD (Wt.)

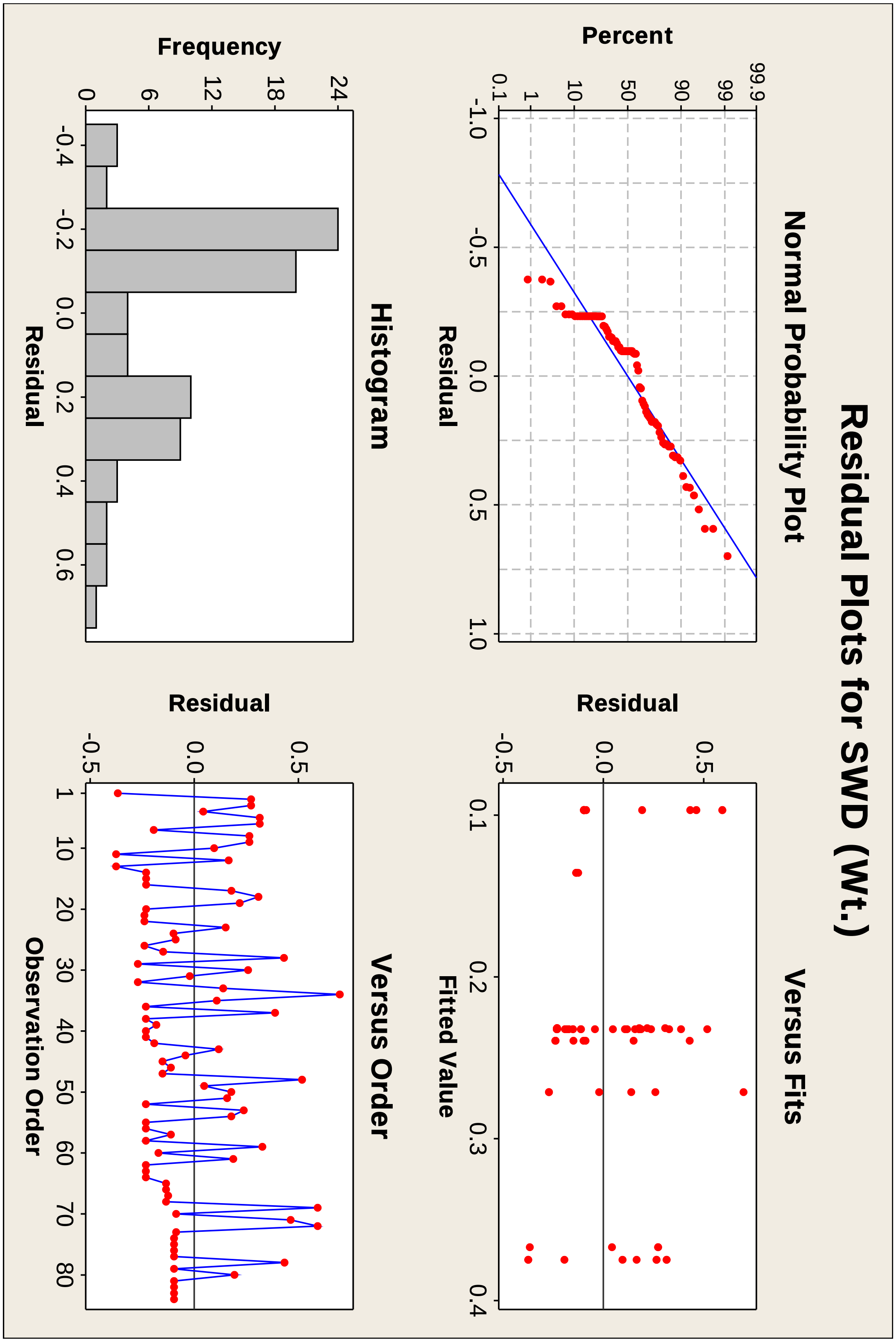
Obs	SWD (Wt.)	Fit	SE Fit	Residual	St Resid
34	0.970000	0.271187	0.085387	0.698813	2.85 R
48	0.750000	0.232336	0.043373	0.517664	2.02 R
69	0.690000	0.096869	0.054103	0.593131	2.34 R
72	0.690000	0.096869	0.054103	0.593131	2.34 R

R denotes an observation with a large standardized residual.

Residual Plots for SWD (Wt.)

4/22/2009 9:11:39 AM

Welcome to Minitab, press F1 for help.
Retrieving project from file: 'K:\Cal Poly\Pikeminnow Thesis Project\Thesis\Minitab Files\SWD ANCOVA 092608 Complete Data - FL Less or Greater.MPJ'


Residual Plots for SWD (Wt.)
Normal Probability Plot
Percent
99.9
99
90
50
10
1
0.1
-1.0
-0.5
0.0
0.5
1.0
Residual
Versus Fits
Residual
0.5
0.0
-0.5
0.1
0.2
0.3
0.4
Fitted Value
Histogram
Frequency
24
18
12
6
0
-0.4
-0.2
0.0
0.2
0.4
0.6
Residual
Versus Order
Residual
0.5
0.0
-0.5
1
10
20
30
40
50
60
70
80
Observation Order

9/10/2008 1:43:56 PM

Welcome to Minitab, press F1 for help.

Regression Analysis: Age versus SPM Length (FL)

The regression equation is
Age = - 0.6235 + 0.01372 SPM Length (FL)

S = 0.715117   R-Sq = 81.7%   R-Sq(adj) = 80.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	45.5903	45.5903	89.15	0.000
Error	20	10.2278	0.5114		
Total	21	55.8182			

Fitted Line: Age versus SPM Length (FL)

Residual Plots for Age

2/17/2009 8:16:00 AM

Welcome to Minitab, press F1 for help.
Retrieving project from file: 'F:\CALPOL~1\PIKEMI~1\THESIS\MINITA~1\SPM LENGTH VS. AGE FITTED LINE PLOT 091008.MPJ'

Regression Analysis: Age versus SPM Length (FL)

The regression equation is
Age = - 0.623 + 0.0137 SPM Length (FL)

Predictor	Coef	SE Coef	T	P
Constant	-0.6235	0.4219	-1.48	0.155
SPM Length (FL)	0.013718	0.001453	9.44	0.000

S = 0.715117   R-Sq = 81.7%   R-Sq(adj) = 80.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	45.590	45.590	89.15	0.000
Residual Error	20	10.228	0.511		
Total	21	55.818			

Predicted Values for New Observations

New Obs	Fit	SE Fit	95% CI	95% PI
1	2.806	0.155	(2.482, 3.130)	(1.279, 4.332)

Values of Predictors for New Observations

```
       SPM
New  Length
Obs    (FL)
  1     250
```

Descriptive Statistics: SPM Length (FL)

```
Variable          N  N*   Mean  SE Mean  StDev  Minimum     Q1  Median     Q3
SPM Length (FL)  22   0  270.8     22.9  107.4    105.0  177.5   282.5  364.3

Variable         Maximum
SPM Length (FL)    445.0
```

2/17/2009 11:38:54 PM

```
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Retrieving project from file: 'H:\Cal Poly\Pikeminnow Thesis
Project\Thesis\Minitab Files\SPM LENGTH VS. AGE FITTED LINE PLOT
091008.MPJ'
```

Regression Analysis: Age versus SPM Length (FL)

```
The regression equation is
Age = - 0.623 + 0.0137 SPM Length (FL)


Predictor            Coef   SE Coef      T      P
Constant          -0.6235    0.4219  -1.48  0.155
SPM Length (FL)  0.013718  0.001453   9.44  0.000


S = 0.715117   R-Sq = 81.7%   R-Sq(adj) = 80.8%


Analysis of Variance

Source          DF      SS      MS      F      P
Regression       1  45.590  45.590  89.15  0.000
Residual Error  20  10.228   0.511
Total           21  55.818


Predicted Values for New Observations

New
Obs    Fit  SE Fit      95% CI          95% PI
  1  3.492   0.158  (3.162, 3.822)  (1.964, 5.020)


Values of Predictors for New Observations

       SPM
New  Length
Obs    (FL)
  1     300
```

4/22/2009 9:29:28 AM

```
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Retrieving project from file: 'K:\Cal Poly\Pikeminnow Thesis
```

Regression Analysis: Nat Log Weight versus Nat Log Fork Length

```
The regression equation is
Nat Log Weight = - 5.387 + 3.154 Nat Log Fork Length


S = 0.0338290   R-Sq = 98.8%   R-Sq(adj) = 98.8%


Analysis of Variance

Source      DF       SS       MS        F      P
Regression   1  8.43262  8.43262  7368.57  0.000
Error       86  0.09842  0.00114
Total       87  8.53104
```

Fitted Line: Nat Log Weight versus Nat Log Fork Length

```
Residual Plots for Nat Log Weight
```

4/22/2009 9:36:39 AM

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Project\Thesis\Minitab Files\SPM LENGTH VS. WT. FITTED LINE PLOT
090908.MPJ'
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9/9/2008 4:39:56 PM

Welcome to Minitab, press F1 for help.

Regression Analysis: Gape (cm) versus Length (FL [mm])

The regression equation is
Gape (cm) = 0.2137 + 0.007000 Length (FL [mm])

S = 0.209552   R-Sq = 77.8%   R-Sq(adj) = 77.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	12.7959	12.7959	291.40	0.000
Error	83	3.6447	0.0439		
Total	84	16.4406			

Fitted Line: Gape (cm) versus Length (FL [mm])

Residual Plots for Gape (cm)

4/22/2009 9:35:06 AM

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